



NOAA's Potential to Help Solve the Climate-Energy Crisis through Renewable Energy Development

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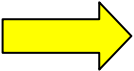
Outline

- Some recent changes in polar regions
 - **Observations**
 - **Arctic**
 - **Understanding and Attribution**
 - **Antarctic and Arctic**
- Atmospheric CO₂ concentration curves
- NOAA's Potential to Support Renewable Energy

IPCC WG1 AR4: Sea Ice

Under several different scenarios (SRES A1B, A2 and B1), large parts of Arctic Ocean are expected to no longer have year-round ice cover by the end of the 21st century.

While projected changes in winter sea ice extent are moderate, late-summer sea ice is projected to disappear almost completely towards the end of the 21st century under the A2 scenario in some models.



Positive feedbacks in the climate system accelerate ice loss.

The ice-albedo feedback allows open water to receive more heat from the Sun during summer, the insulating effect of sea ice is reduced and the increase in ocean heat transport to the Arctic further reduces ice cover.

Model simulations indicate that the late-summer sea ice cover decreases substantially and generally evolves over the same time scale as global warming. Antarctic sea ice extent is also projected to decrease in the 21st century. {8.6, 10.3, Box 10.1}

Arctic Summer Sea Minimum

- IPCC: “While projected changes in winter sea ice extent are moderate, late-summer sea ice is projected to disappear almost completely towards the end of the 21st century under the A2 scenario in some models.”
- Since IPCC AR4, Arctic summer minimum (2007) was much lower than recent minima -- lowest since satellites began observing in 1979
 - **The average sea ice extent for the month of September was 4.28 million square kilometers (1.65 million square miles), the lowest September on record, shattering the previous record for the month, set in 2005, by 23 percent**
- 2008 almost as low as 2007

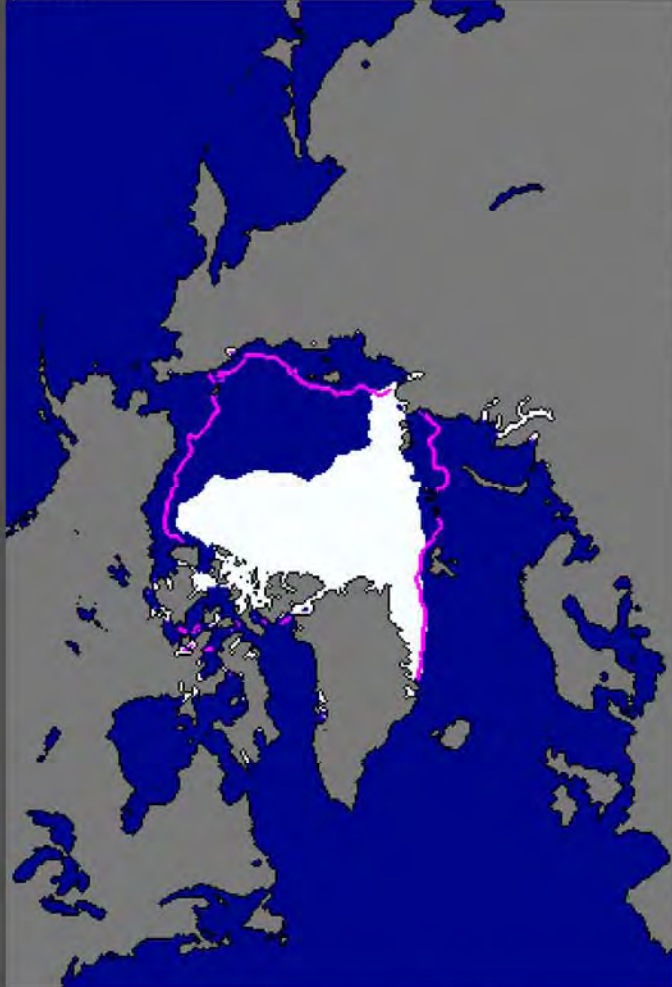
Arctic Sea Ice Minimum



2007 Sept

2005 Sept

Sea Ice Extent
Sep 2007

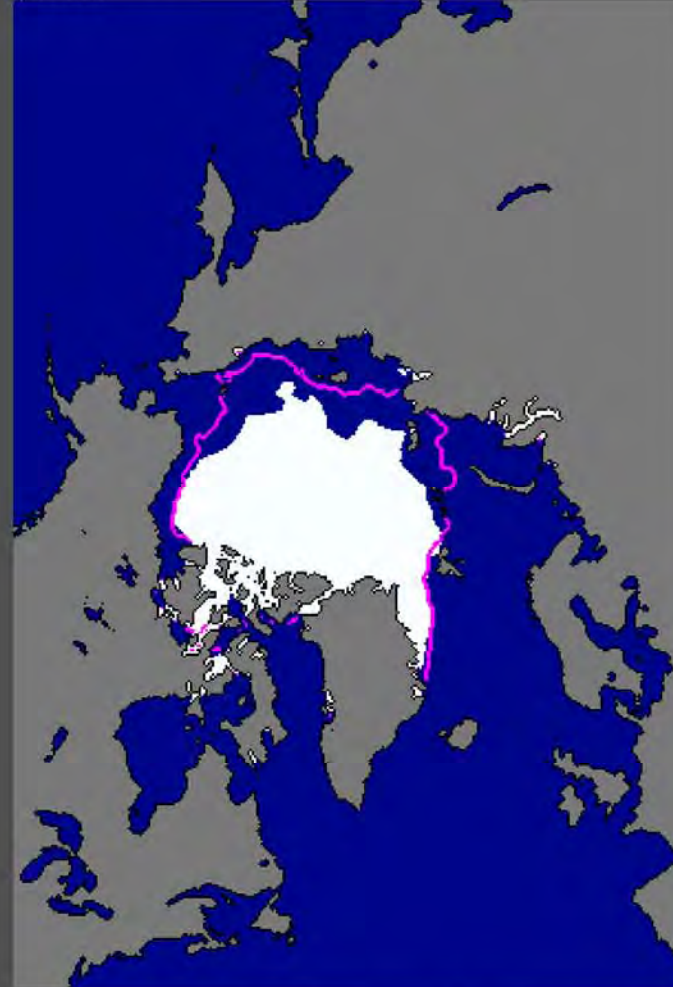


National Snow and Ice Data Center, Boulder, CO

median
ice edge

Total extent = 4.3 million sq km

Sea Ice Extent
Sep 2005



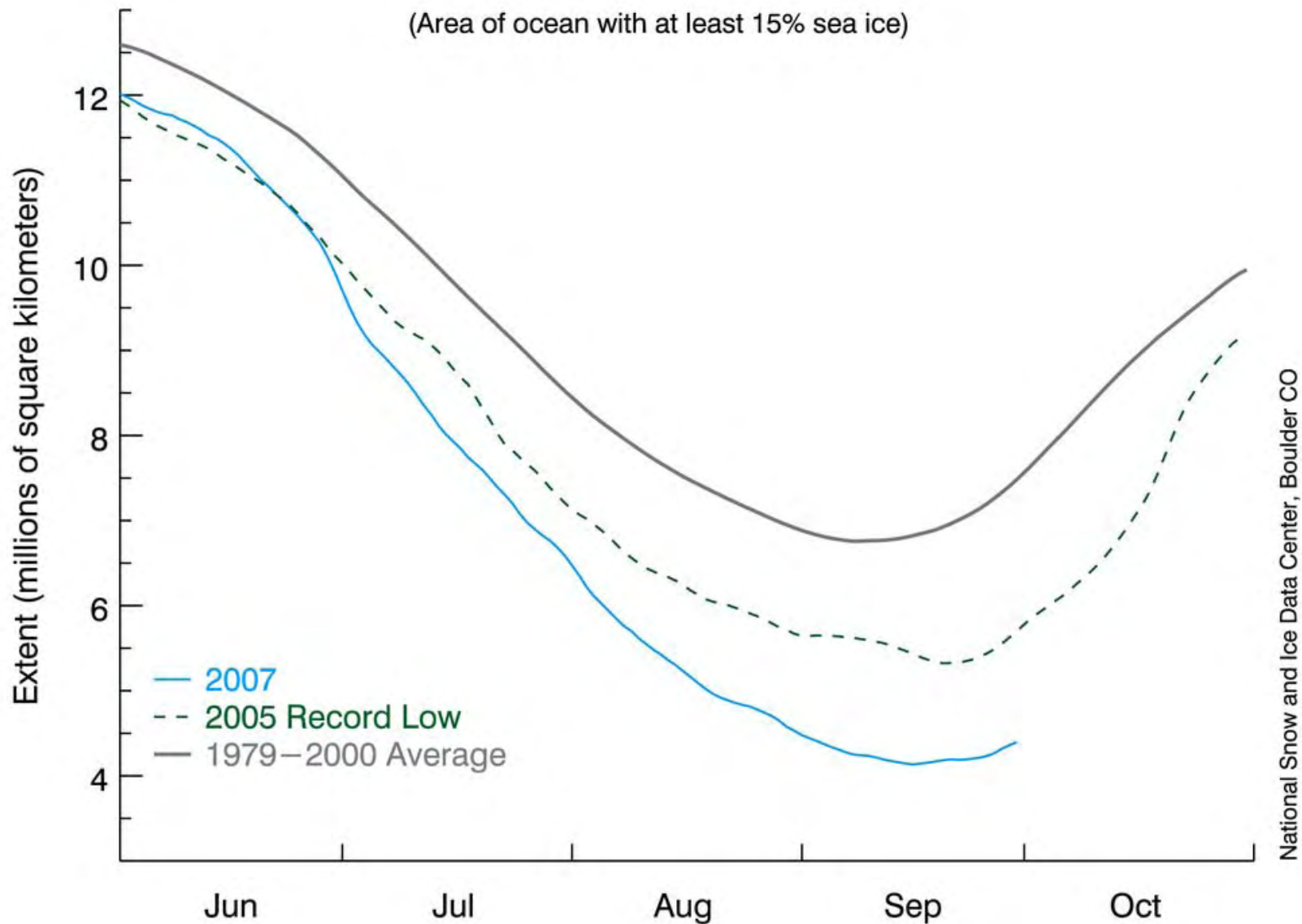
National Snow and Ice Data Center, Boulder, CO

median
ice edge

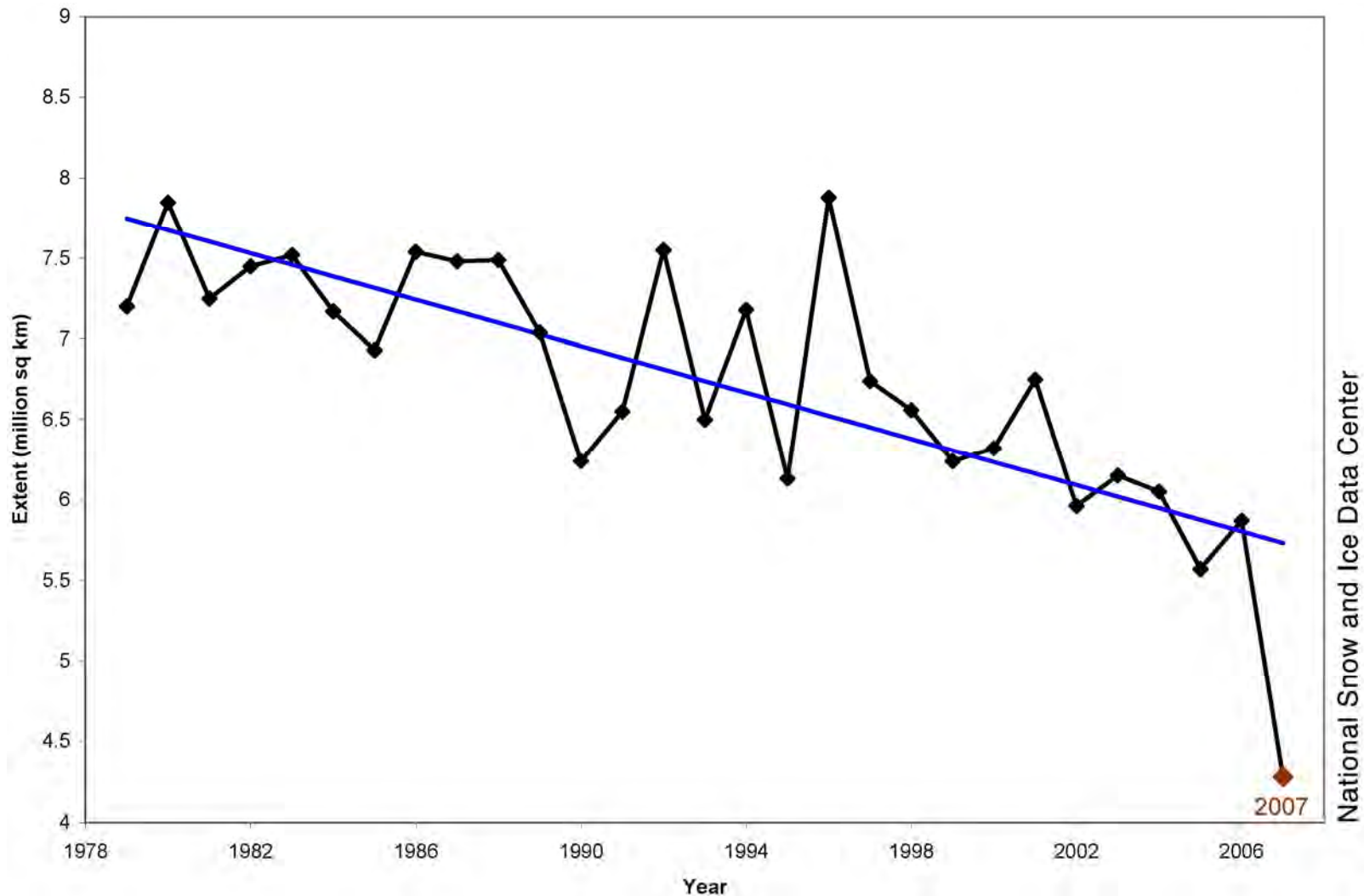
Total extent = 5.6 million sq km

Arctic Sea Ice Extent

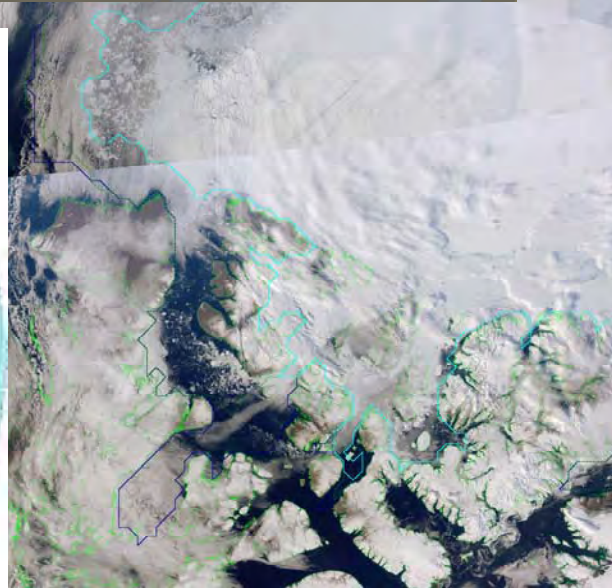
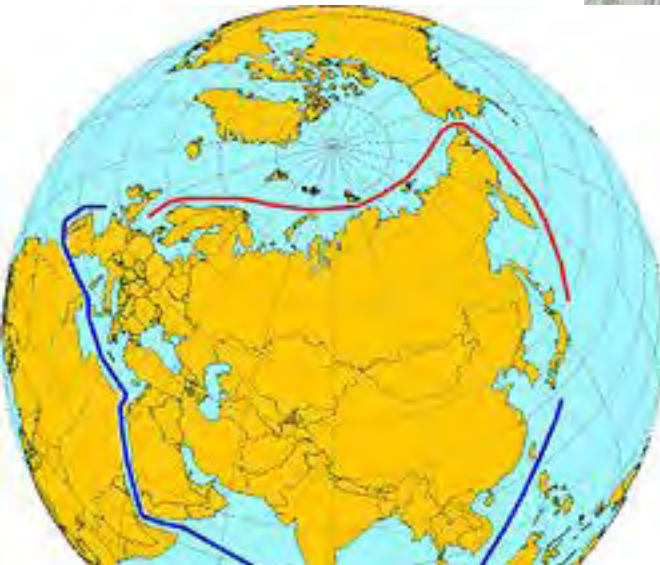
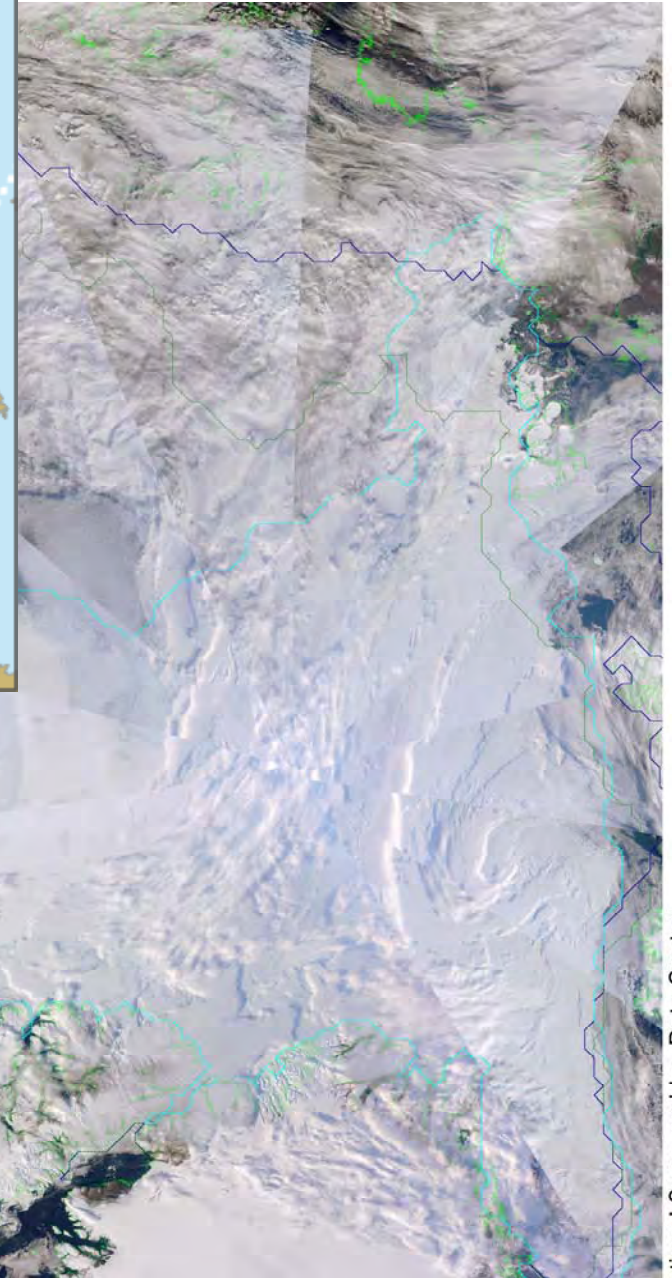
(Area of ocean with at least 15% sea ice)



In 2007, September rate of sea ice decline since 1979 is approximately 10 percent per decade



In 2007, Northwest Passage opened



Reasons for the greatly reduced 2007 Arctic Sea Ice Minimum

1. Pre-conditioning

- Years of shrinking and thinning in a warm climate

2. Unusual atmospheric pattern

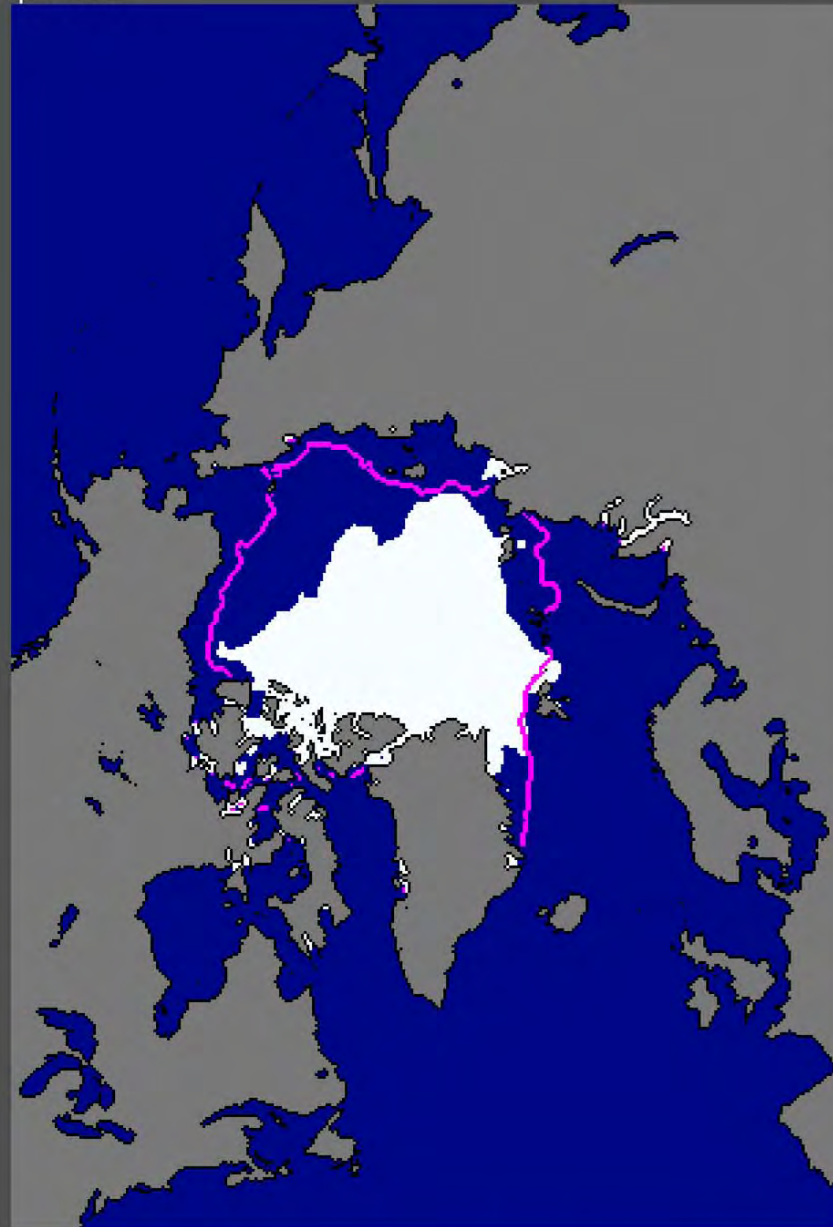
- Persistent high atmospheric pressures over the central Arctic Ocean
- Lower pressures over Siberia
- Clear skies under the high-pressure cell, promoting strong melt.
- Anomalous winds pumped warm air into the region
 - Warm winds -> further melt
 - Warm winds -> pushed ice away from the Siberian shore.
 - Warm winds -> unusually large area of thin ice and open water.

3. Ice-albedo feedback

- Thin ice and open water allow more surface heating because of much lower albedo than ice, leading to increased melting of ice.

2008 Arctic Sea Ice Minimum

Sea Ice Extent
Sep 2008

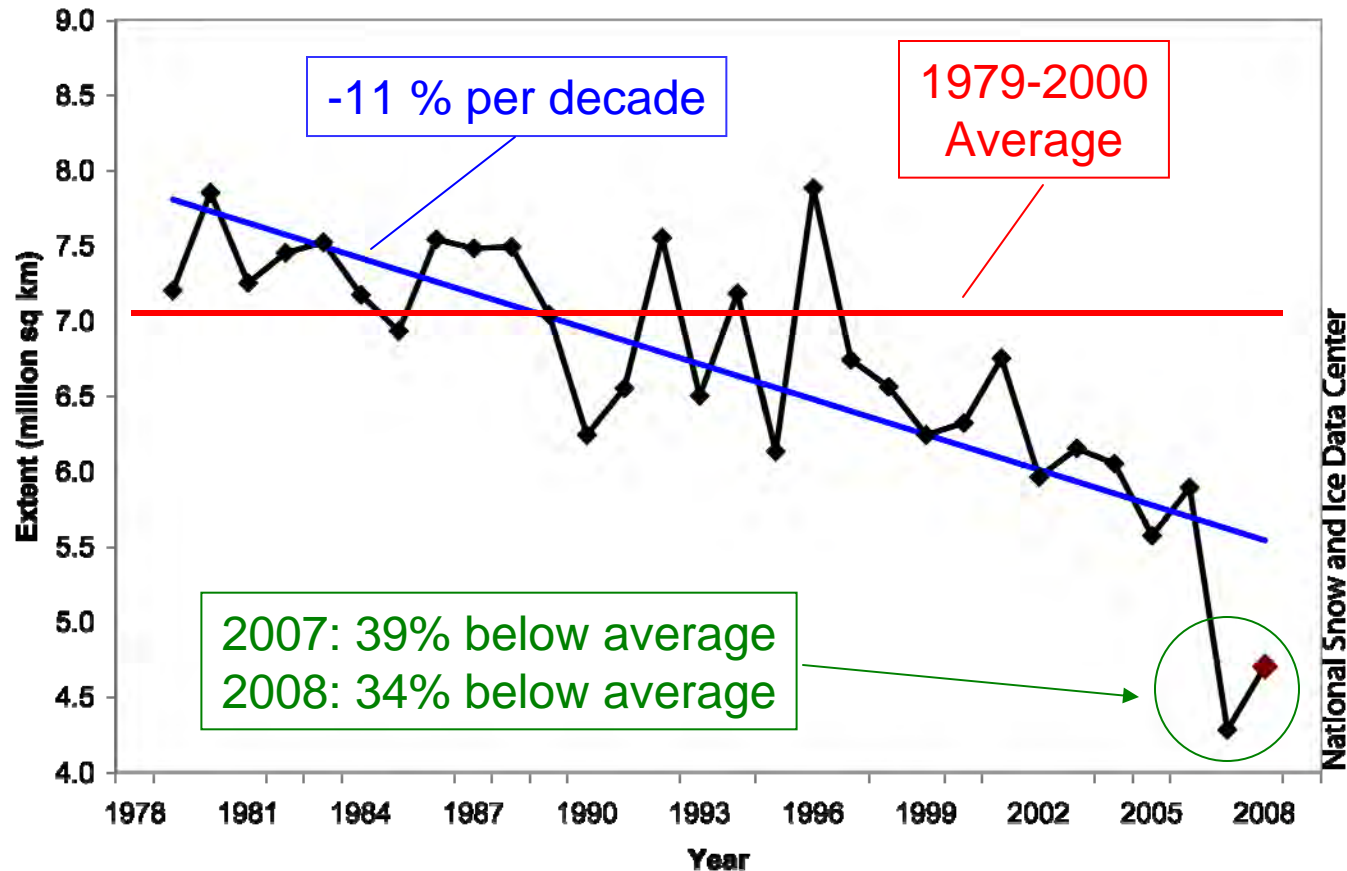


National Snow and Ice Data Center, Boulder, CO

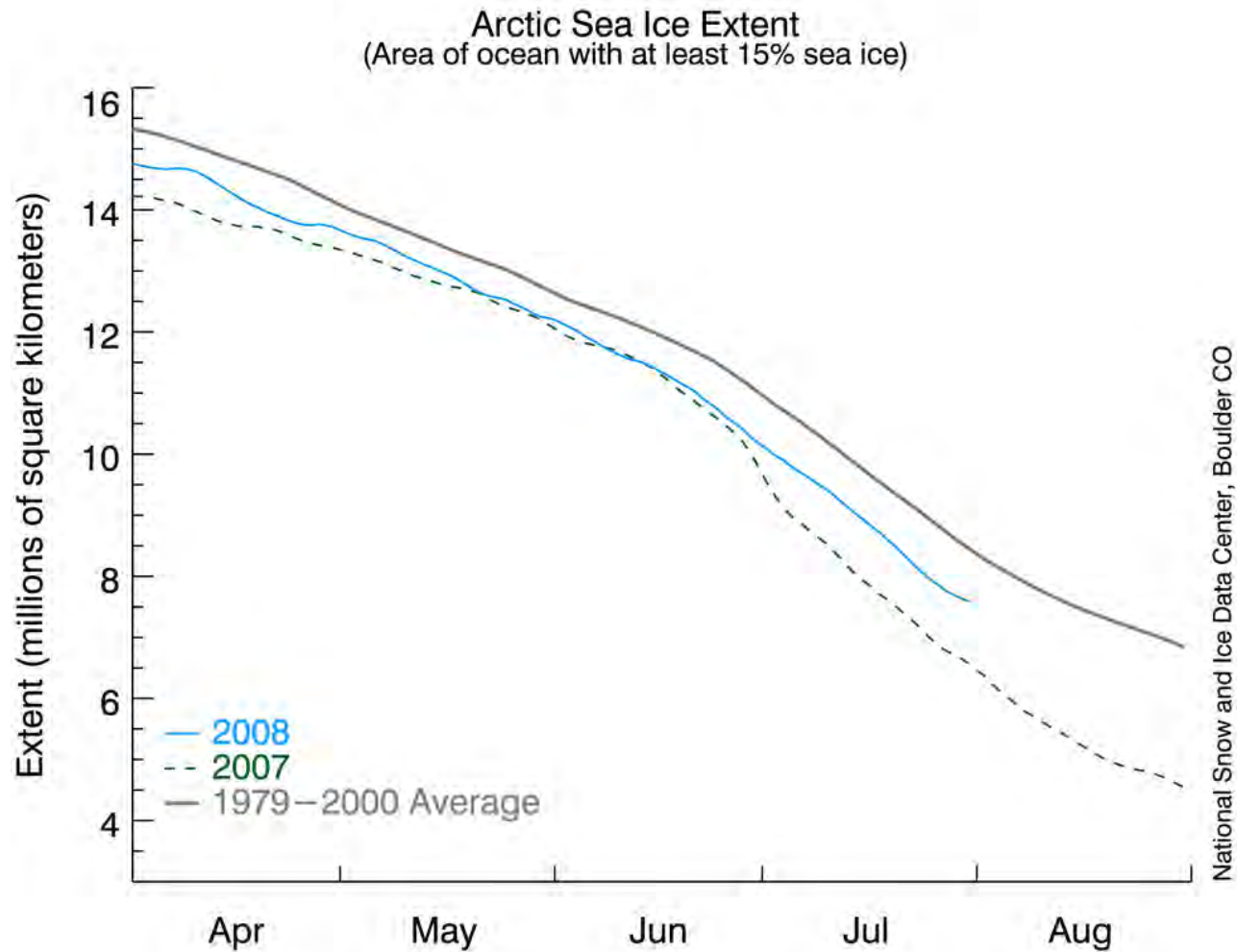
median
ice edge

Total extent = 4.7 million sq km

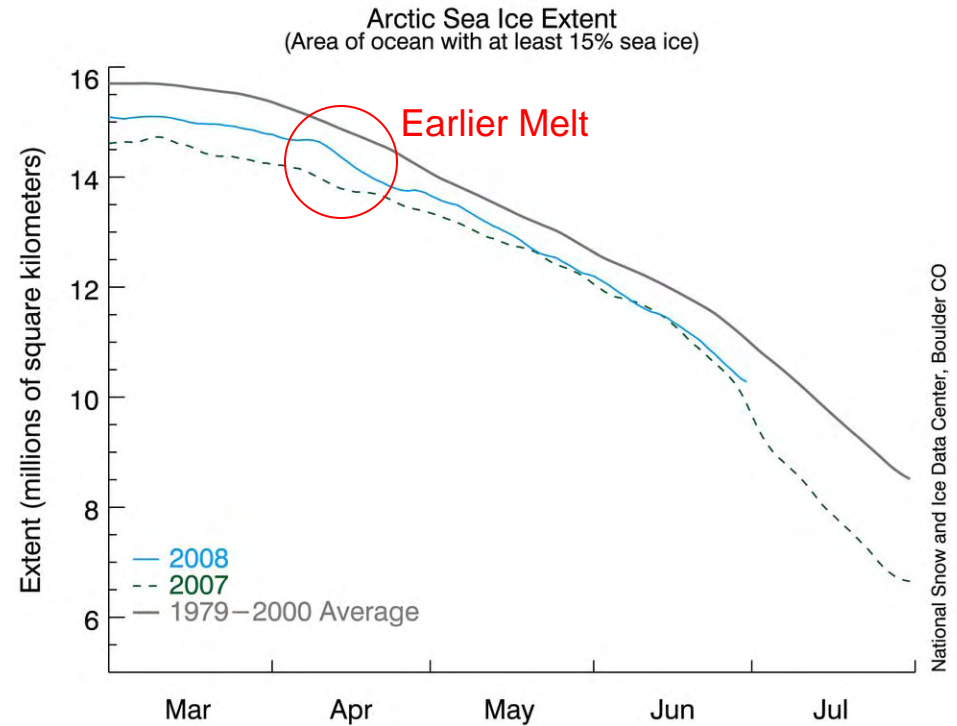
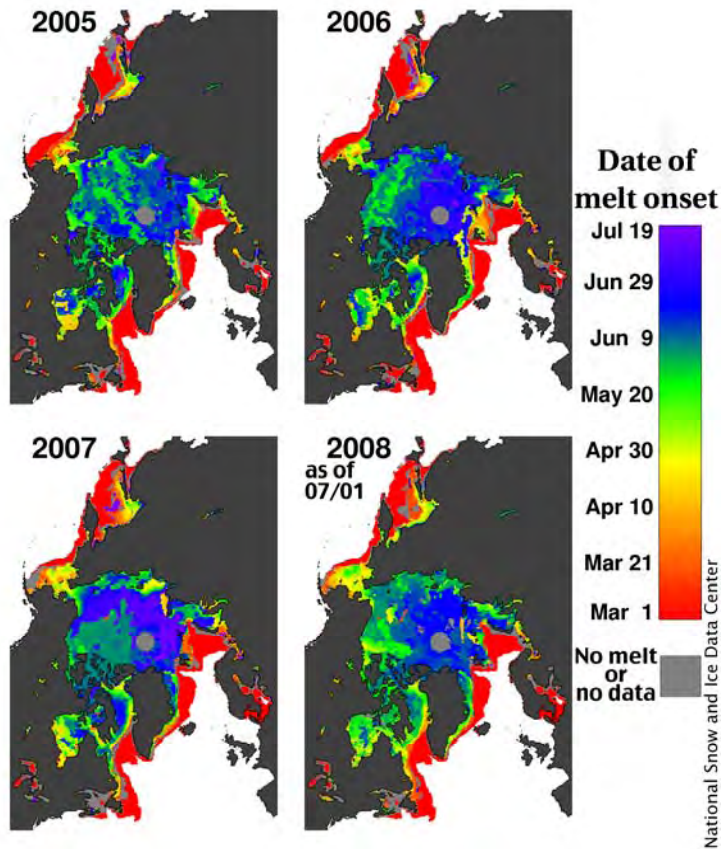
Because the 2008 low was so far below the September average, the negative trend in September extent has been pulled downward, from -10.7% per decade to -11.8% per decade



2008, 2007, and average 1979-2000



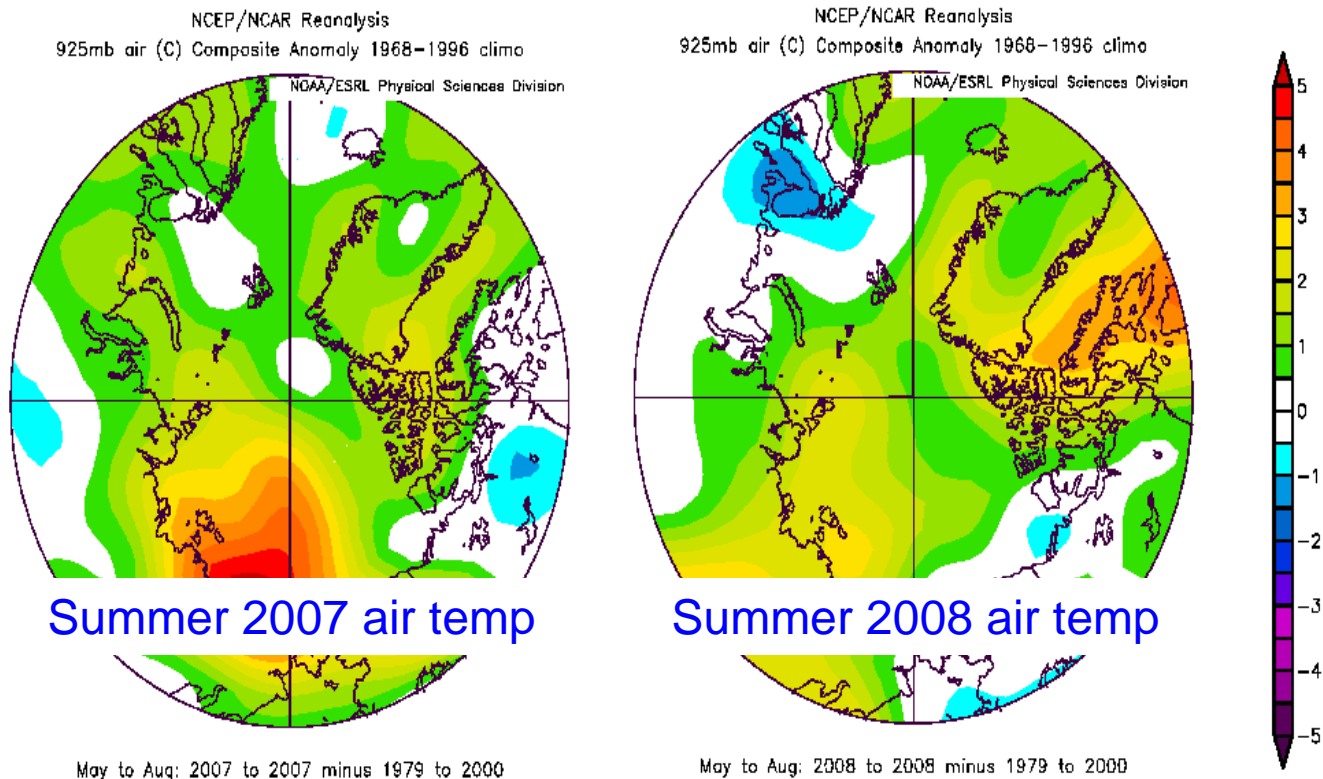
2008 Arctic Sea Ice Melt started earlier than average



Thanks to T. Markus, NASA Goddard for melt data

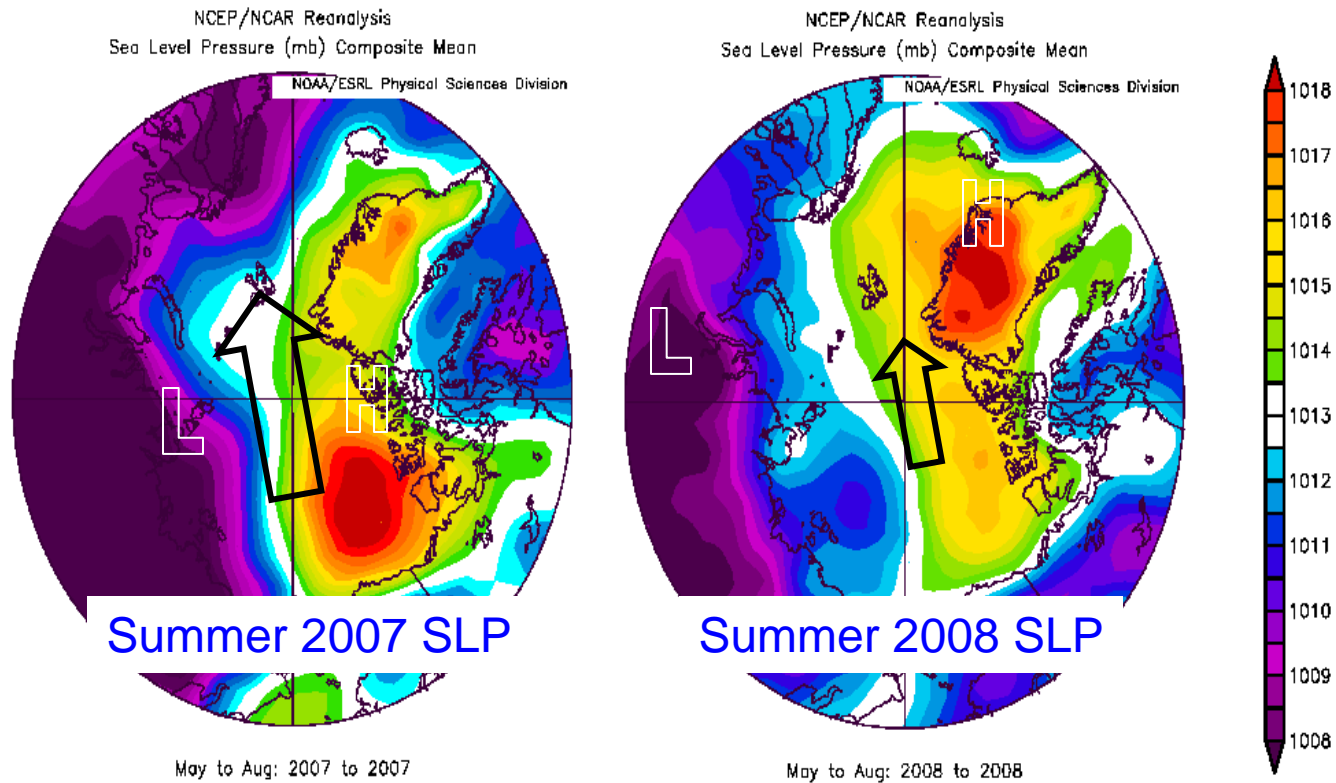
2008 atmospheric conditions were not as favorable for extreme ice loss as they were in 2007

Cooler Temperatures

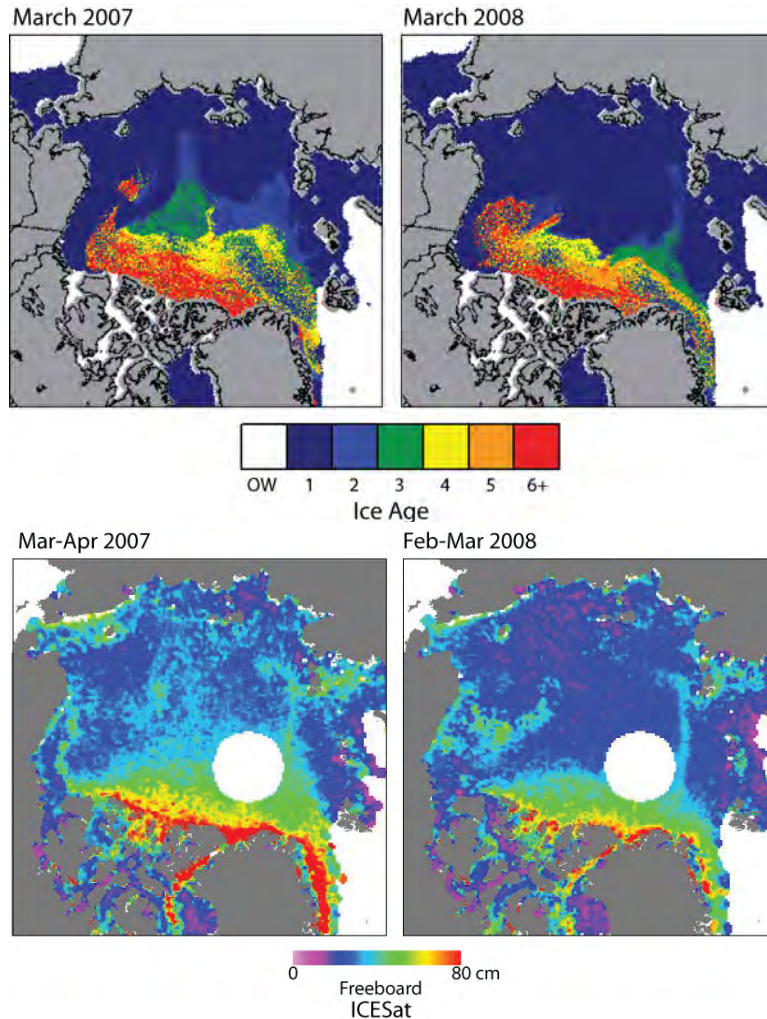


2008 atmospheric conditions were not as favorable for extreme ice loss as they were in 2007

Weaker Winds



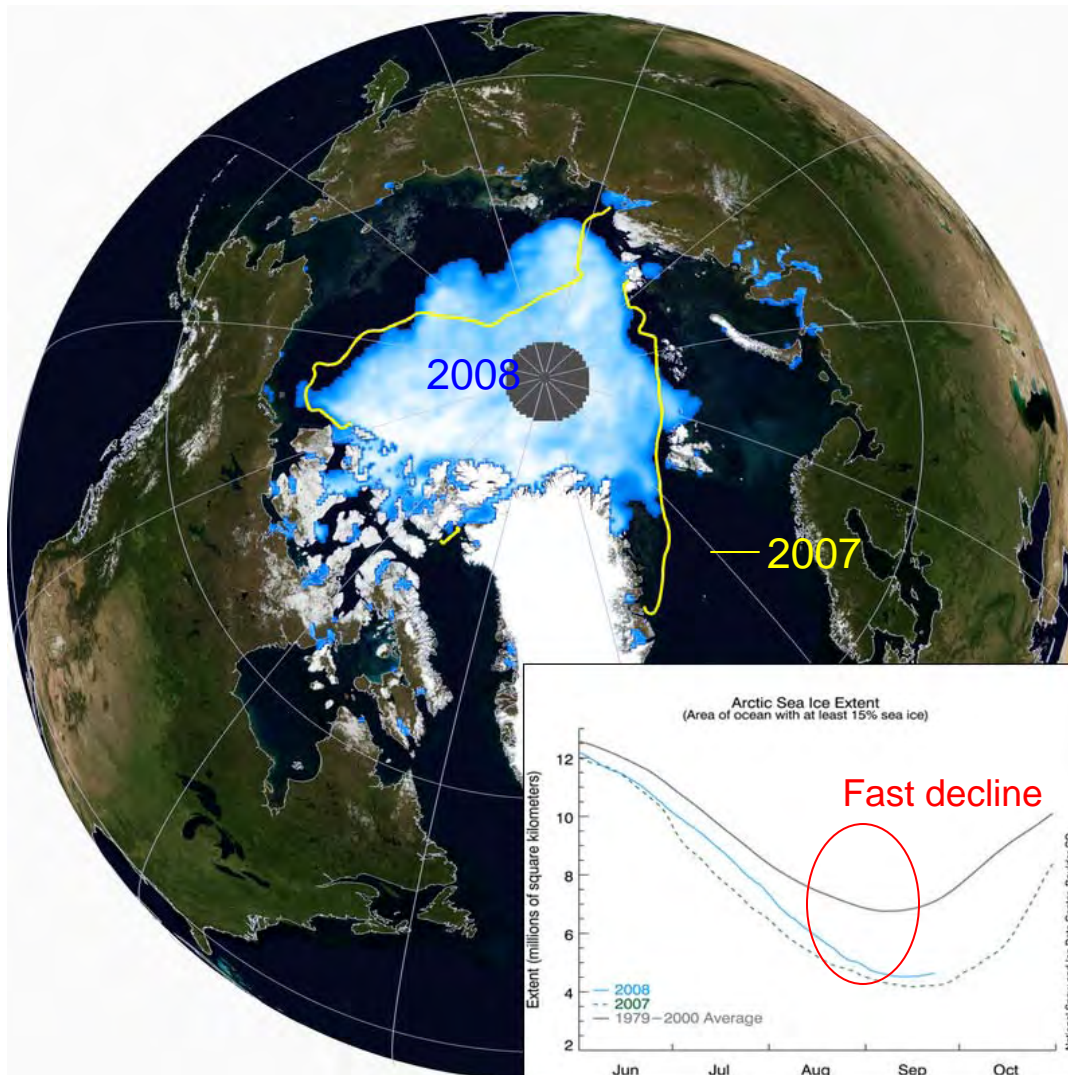
Even younger and thinner ice at end of winter 2008



Tracking of sea ice shows that in the 1980s 40% of the Arctic Basin was seasonal ice (grows and melts completely each year); now it's 73%

This younger ice is thinner: seasonal ice was 20 cm thinner in 2008 and perennial ice (remains through the summer) was 50 cm thinner

Fast August decline = near record minimum



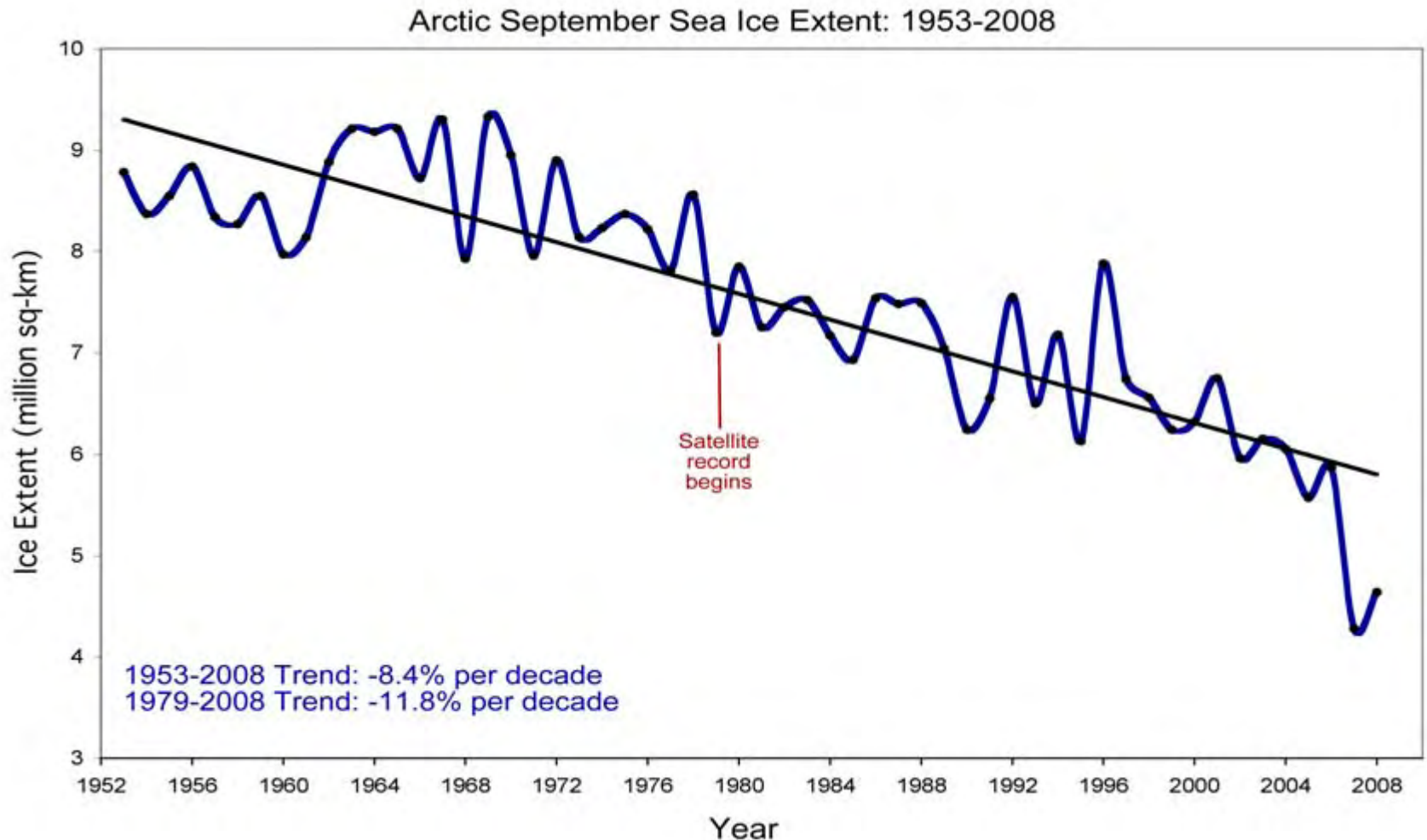
9% more ice than in 2007

- 2nd lowest in satellite record

- 34% less than 1979-2000 climatology

- Thinner ice melted more easily, so even under non-optimal melt conditions, a near-record low extent occurred

Current Trend in September Sea Ice Extent

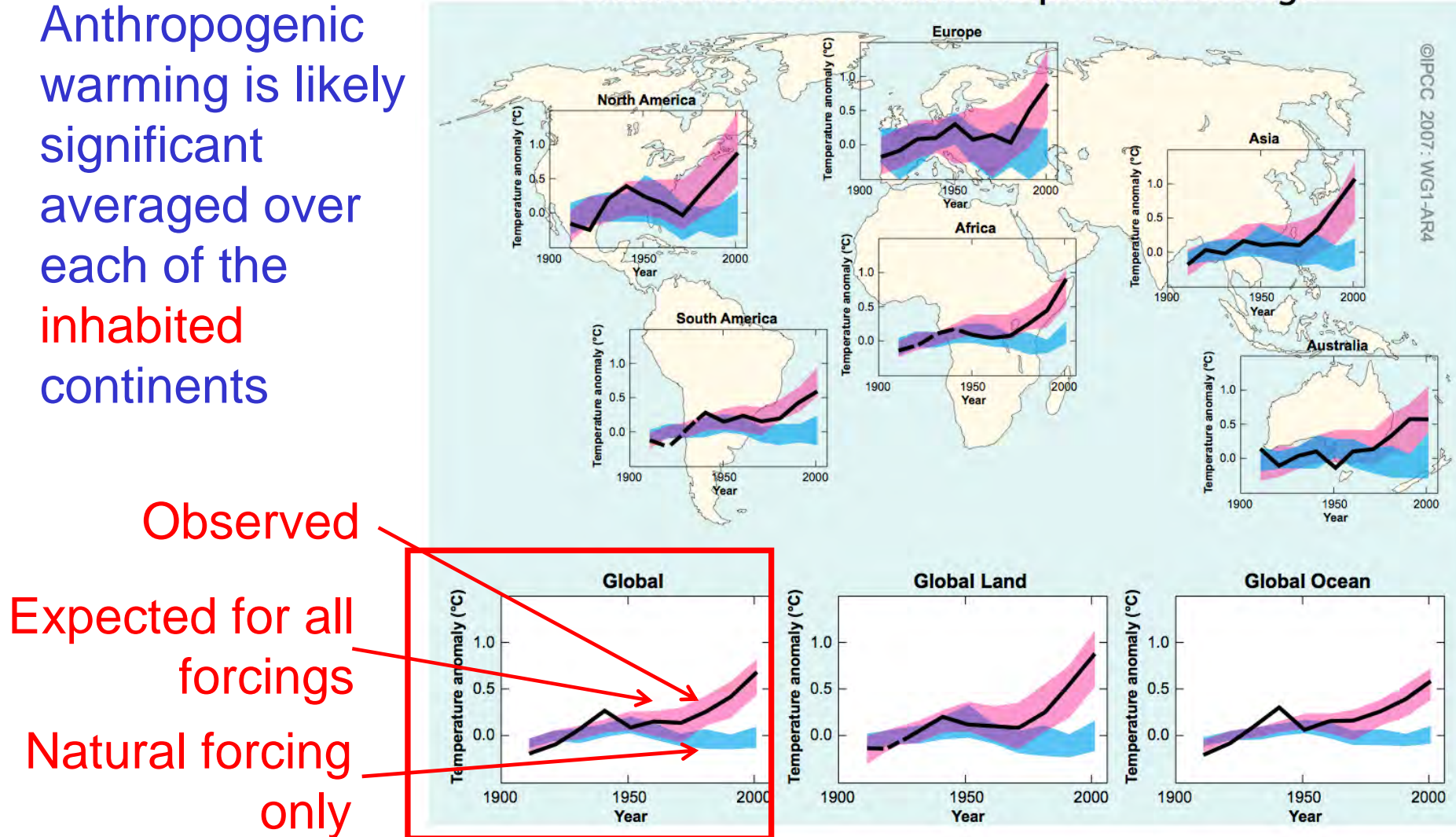


Adapted from UK Hadley Centre

Understanding and Attributing Climate Change: *Antarctic is excepted here (IPCC WG1 AR4)*

Anthropogenic warming is likely significant averaged over each of the **inhabited** continents

Global and Continental Temperature Change





Attribution of polar warming to human influence: Arctic & Antarctic

Attribution of polar warming to human influence

NATHAN P. GILLETT, DAVID A. STONE, PETER A. STOTT, TORU NOZAWA, ALEXEY YU. KARPECHKO, GABRIELE C. HEGERL, MICHAEL F. WEHNER AND PHILIP D. JONES

“The IPCC Fourth Assessment Report concluded that ‘Anthropogenic influence has been detected in every continent except Antarctica (which has insufficient observational coverage to make an assessment)’. Our findings demonstrate that **anthropogenic influence is detectable in Antarctic land surface temperature, and distinguishable from a naturally forced response**, even given the limited station network and short period for which data are available...”

- nature geoscience VOL 1 NOVEMBER 2008
www.nature.com/naturegeoscience



Attribution of polar warming to human influence: Arctic & Antarctic

- Several studies have noted a rise in Arctic temperatures over recent decades, but have not formally attributed the changes to human influence, owing to sparse observations and large natural variability.
- Up-to-date gridded data set of land surface temperatures and simulations from four coupled climate models to assess the causes of the observed polar temperature changes.
- Observed changes in Arctic and Antarctic temperatures are not consistent with internal climate variability or natural climate drivers alone, and are directly attributable to human influence.
- Human activities have already caused significant warming in both polar regions, with likely impacts on polar biology, indigenous communities, ice-sheet mass balance and global sea level.

From Gillette et al., nature geoscience
VOL 1 NOVEMBER 2008
www.nature.com/naturegeoscience

Arctic

Antarctic

a, b:
observed
trends

c,d : simulated
ALL trends

e,f : simulated
NAT trends

g,h : observed
trends
calculated in
same way up to
July 2008

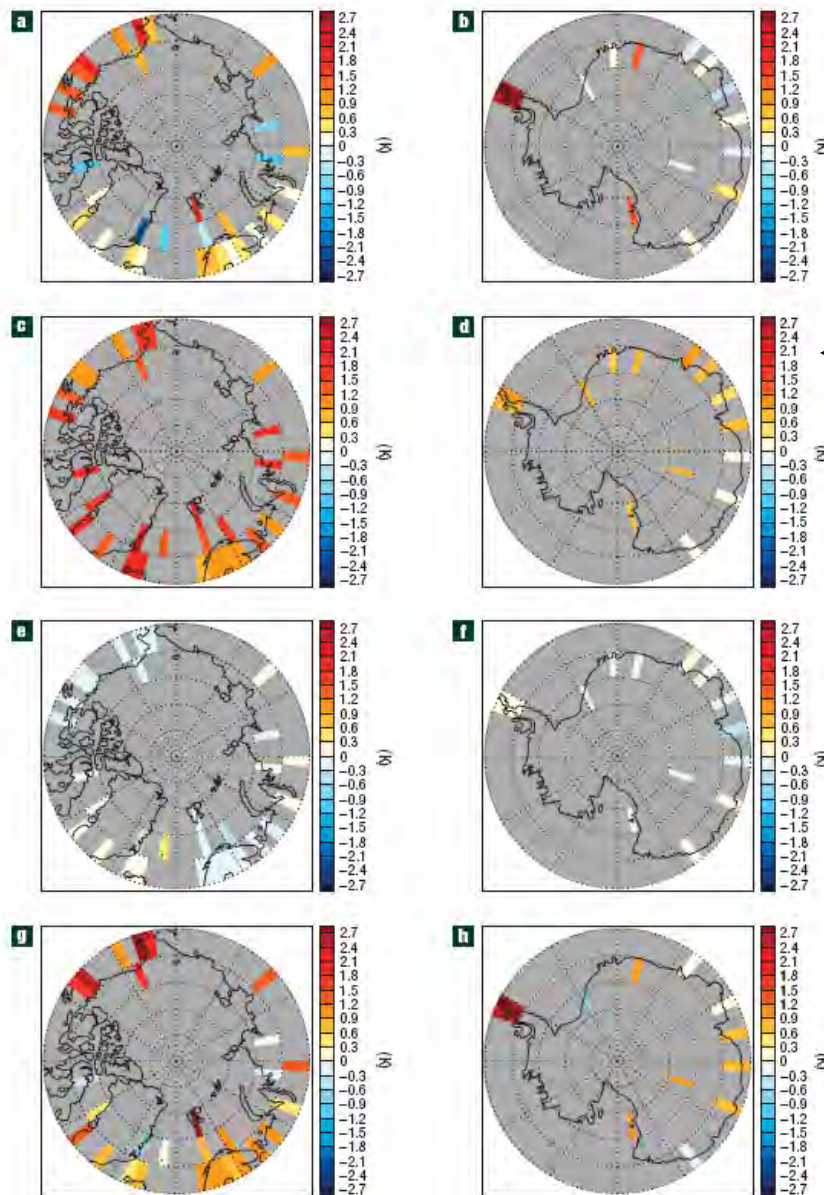


Fig.
2b

Fig.
2d

In the Antarctic, whereas the ensemble mean of the model simulations shows warming everywhere (Fig. 2d), the observations show strong warming on the Antarctic Peninsula, cooling at the South Pole, and a mixture of positive and negative trends elsewhere, although positive trends predominate (Fig. 2b).

nature geoscience
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Figure 2 Simulated and observed grid cell temperature trends. Trends were calculated for grid cells with at least 70% of 5-yr means present in the Arctic (1900–1999) and Antarctic (1950–1999). a–f, Observed trends (a,b), simulated ALL trends (c,d) and simulated NAT trends (e,f). In b, locally significant warming at the 5% level, allowing for autocorrelation, was found in the cells containing the stations Vernadsky, Rothera, Novoladskaja and Byrd, with significant cooling at the South Pole. g,h, Observed trends calculated in the same way up to July 2008.



Impact of stratospheric ozone hole recovery on Antarctic climate

- Models of strat. polar ozone depletion & anthropogenic GHG have both contributed to the observed increase of summertime tropospheric westerlies in the South. Hemis. (SH) with the ozone influence dominating.
- As the stratospheric halogen loading decreases in the future, ozone is expected to return to higher values, with the disappearance of the Antarctic ozone hole.
- The impact of this ozone recovery on SH climate is investigated using 21st century simulations with a chemistry climate model (CCM).
- The model response to the ozone recovery by 2100 shows that tropospheric circulation changes during austral summer caused by ozone depletion between 1970 and 2000 almost reverse, despite increasing GHG concentrations.
- Comparison of the CCM results with multi-model scenario experiments from the IPCC AR4 emphasize the importance of stratospheric ozone recovery for Antarctic climate.

From Perlwitz, J., S. Pawson, R. L. Fogt, J. E. Nielsen, and W. D. Neff (2008), Impact of stratospheric ozone hole recovery on Antarctic climate,

Geophys. Res. Lett., 35, L08714, doi:10.1029/2008GL033317.

Perlwitz et al.

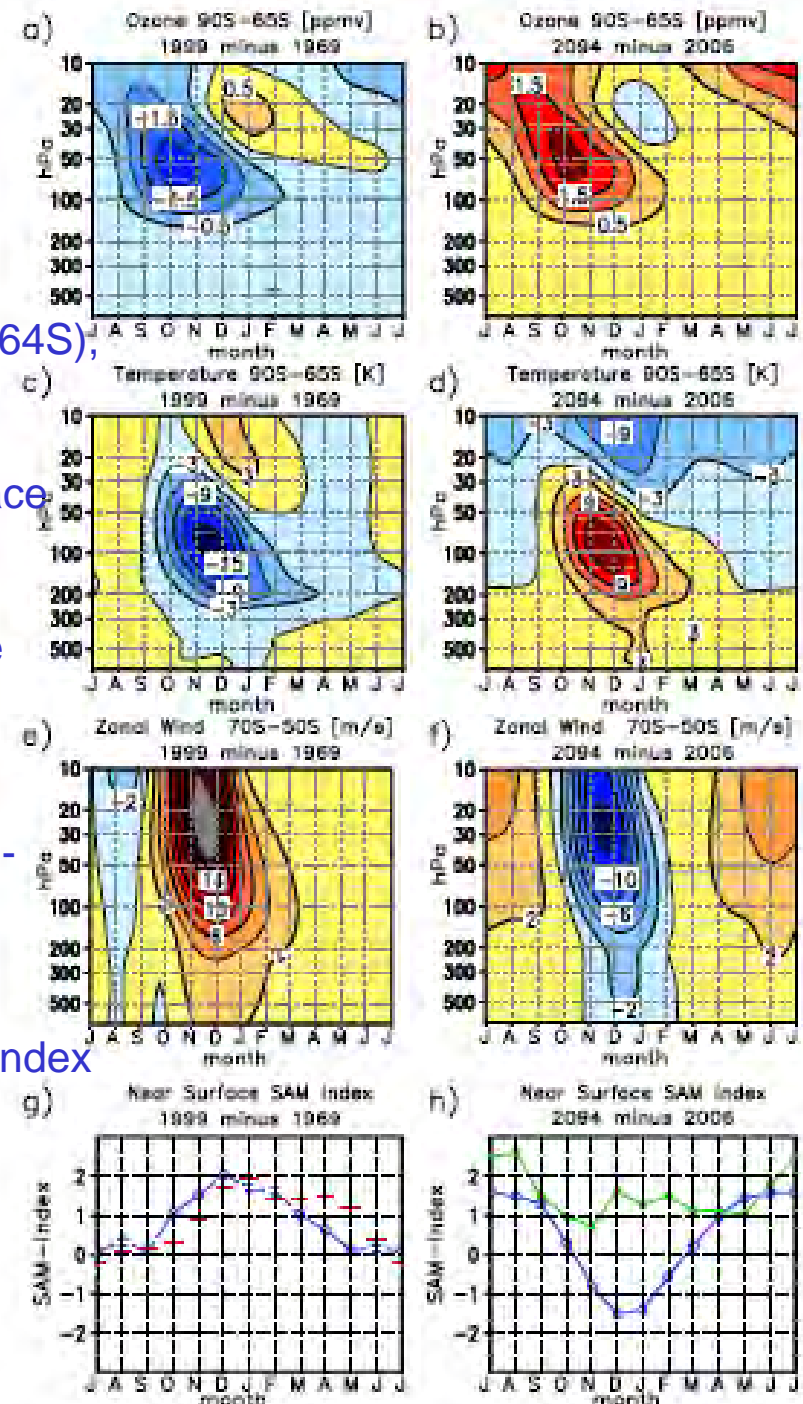
Monthly changes in (a and b) polar cap ozone (90S–64S), (c and d) polar cap temperature (90S–64S), (e and f) mid-latitude zonal wind (70S–50S), and (g and h) 3-month overlapping changes of near surface SAM index (blue lines in Figures 2g and 2h).

Figures 2a, 2c, 2e, and 2g are for period I (ensemble mean [P-1,P-2]),

Figures 2b, 2d, 2f, and 2h are for period II (ensemble mean [C21-HSST,C21-CSST]).

Red crosses in Figure 2g indicate observed changes in SAM index based on Marshall index [Marshall, 2003].

Green line in Figure 2h indicates values for C21C1960. Labels in Figures 2g and 2h indicate center month of 3-month mean.





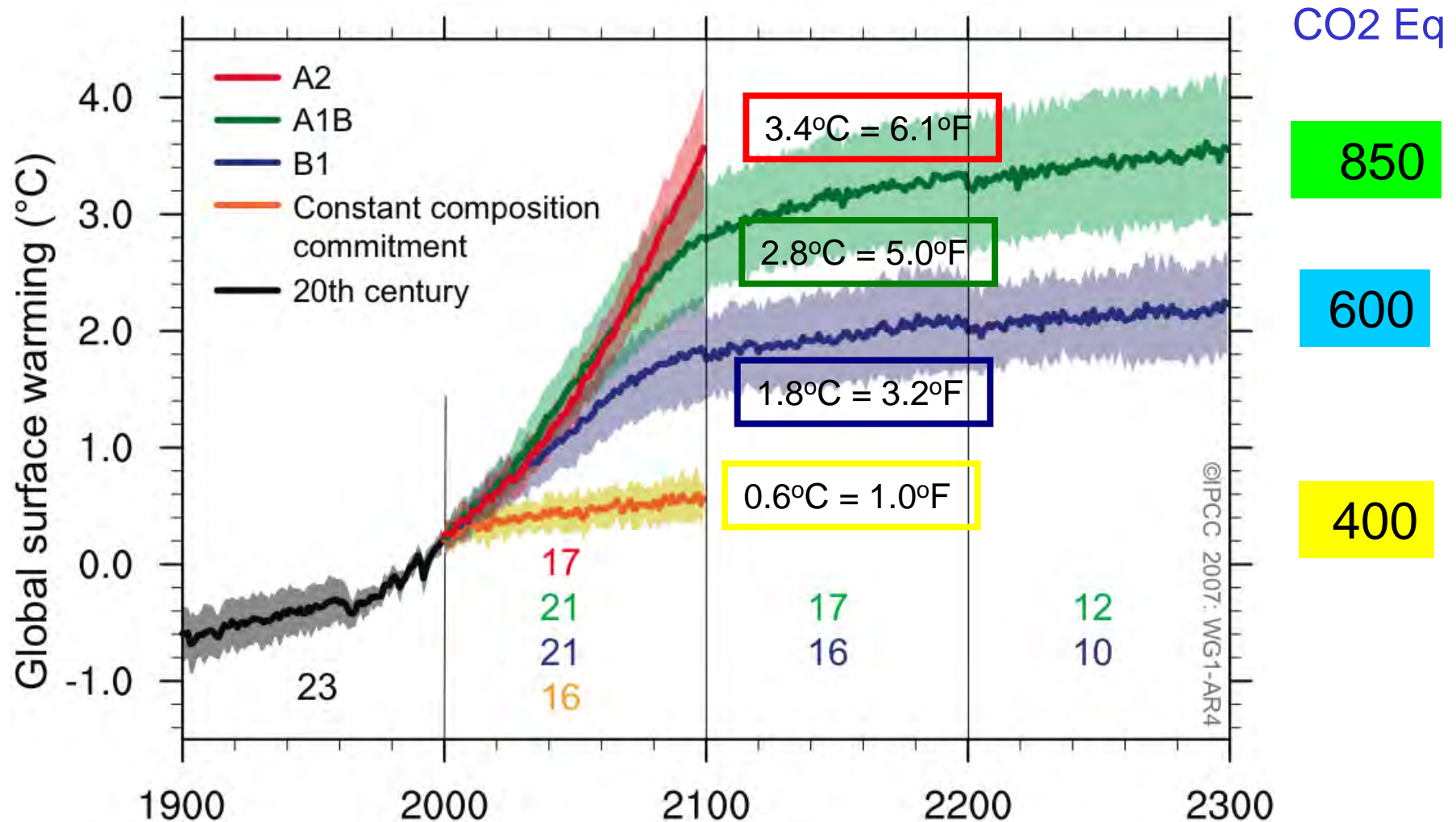
Impact of stratospheric ozone hole recovery on Antarctic climate

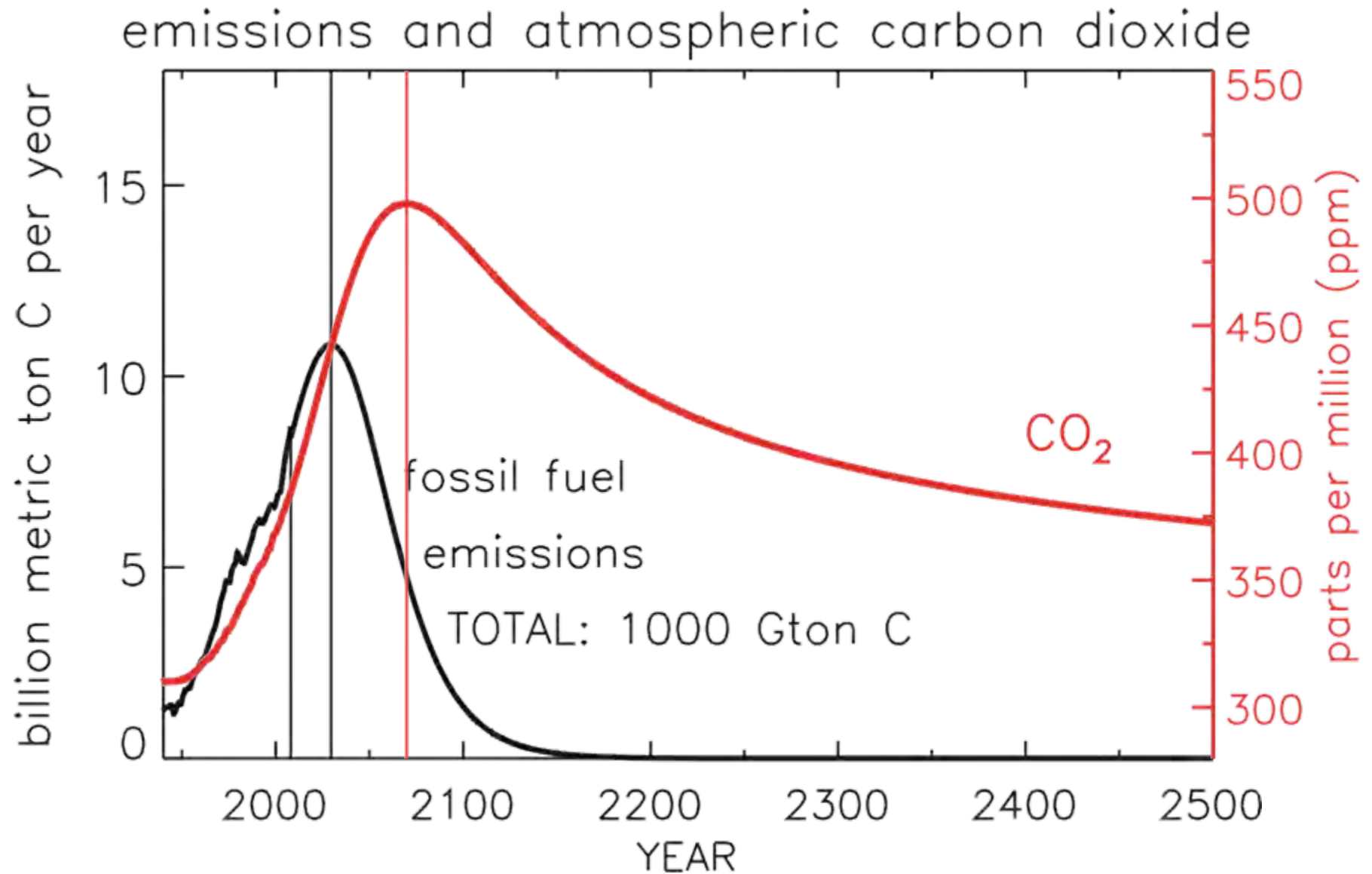
- A full recovery of the stratospheric ozone hole could modify climate change in the SH and amplify Antarctic warming.
- While Earth's average surface temperatures have been increasing, the interior of Antarctica has exhibited a unique cooling trend during the austral summer and fall caused by ozone depletion
- **"If the successful control of ozone-depleting substances allows for a full recovery of the ozone hole over Antarctica, we may finally see the interior of Antarctica begin to warm with the rest of the world," Perlwitz said**
- Perlwitz, J., S. Pawson, R. L. Fogt, J. E. Nielsen, and W. D. Neff (2008), Impact of stratospheric ozone hole recovery on Antarctic climate, *Geophys. Res. Lett.*, 35, L08714, doi:10.1029/2008GL033317.

Shift attention to possible CO₂
concentration curves and stabilisation
levels

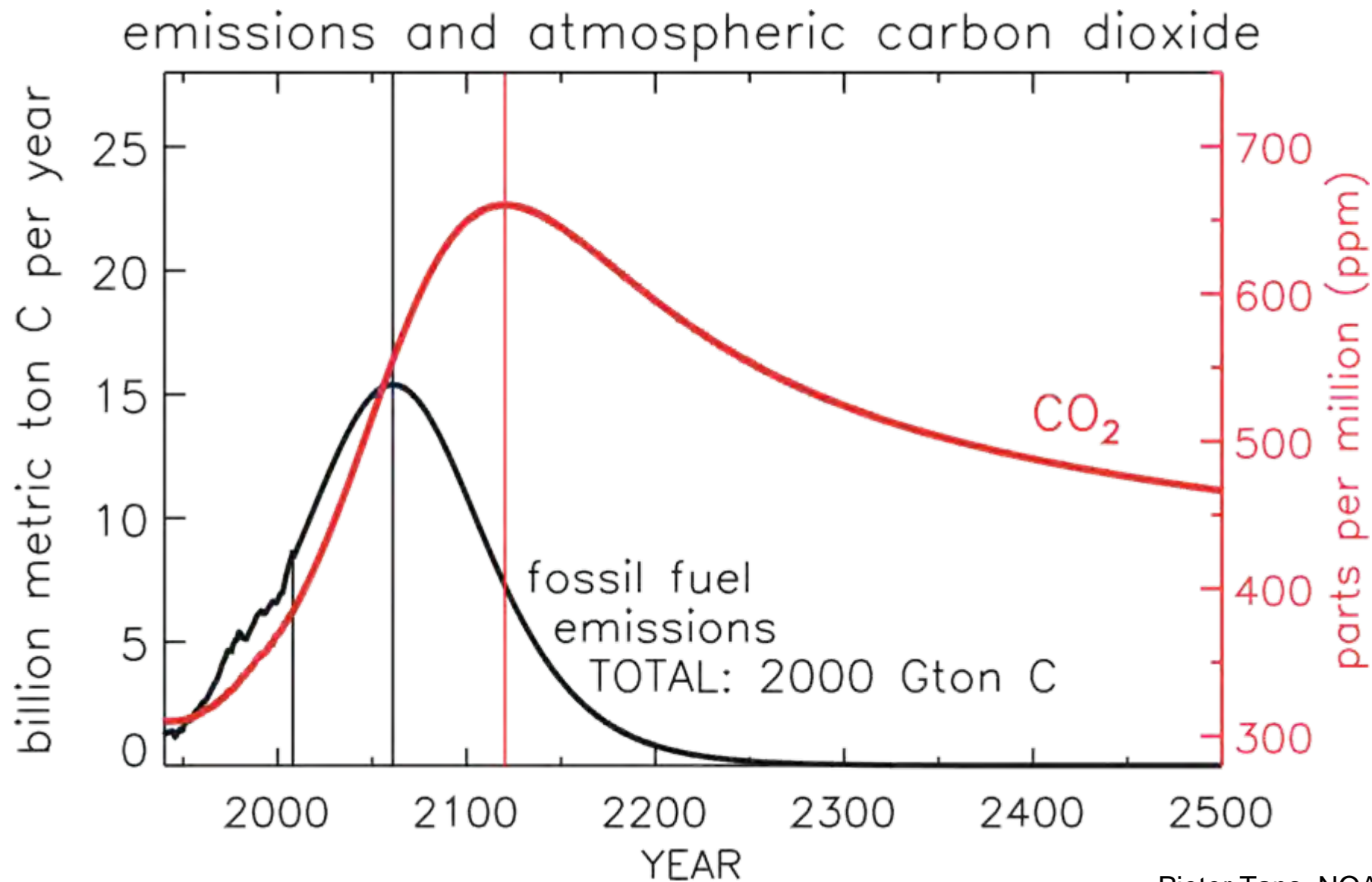
IPCC Figure TS.32 = Fig. 10.4, with ppms added

Warming will increase if GHG increase. If GHG were kept fixed at current levels, a committed 0.6°C of further warming would be expected by 2100. More warming would accompany more emission.



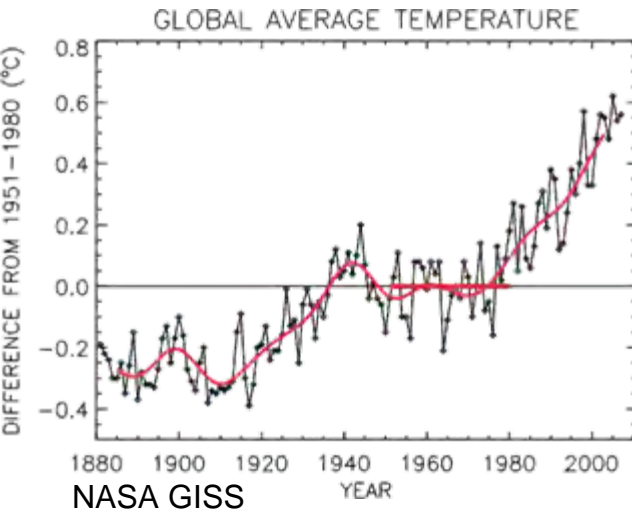


What if “unconvention” FF are developed, e.g., deep offshore, extra heavy oil (Venezuela), tar sands (Canada), and Shale Oil (U.S.) → double reserves from 1,000 to 2,000 Gt C

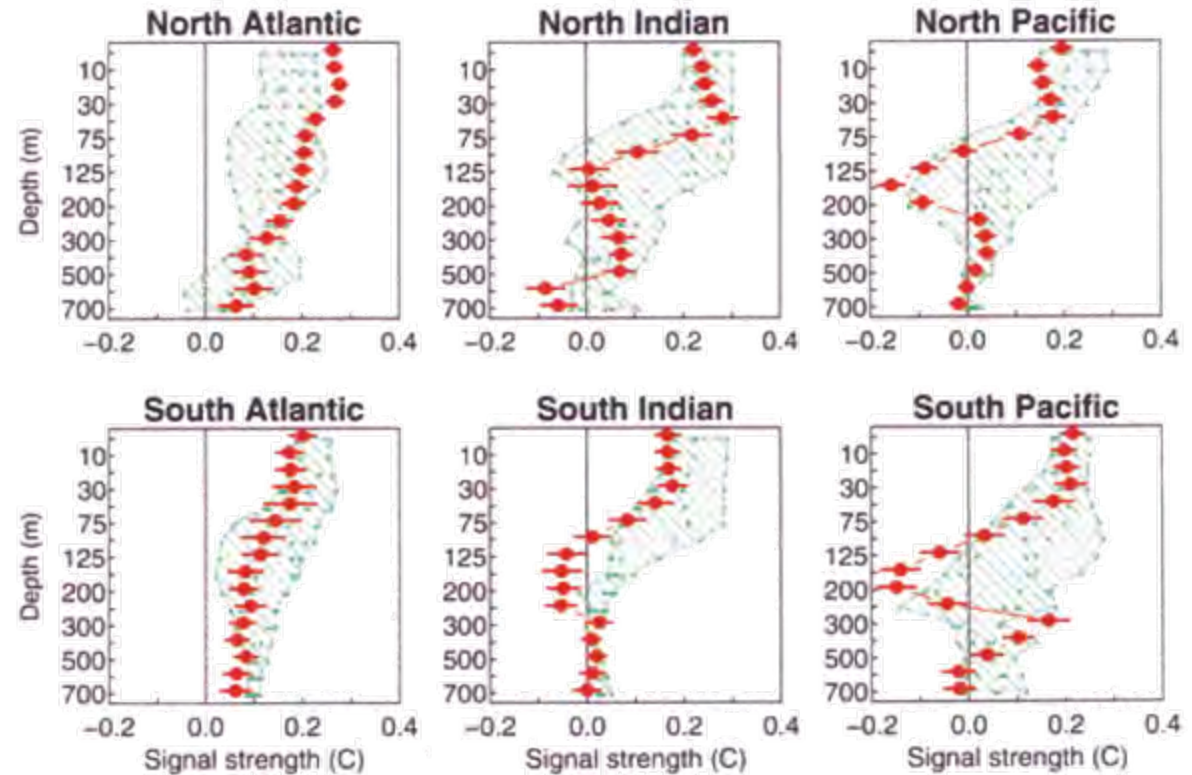


Climate system includes inherent lag-times

Atmosphere



Observed and modeled ocean warming since 1960



At the current rate of atmos T increase the ocean surface is lagging the atmosphere by about 15 years.

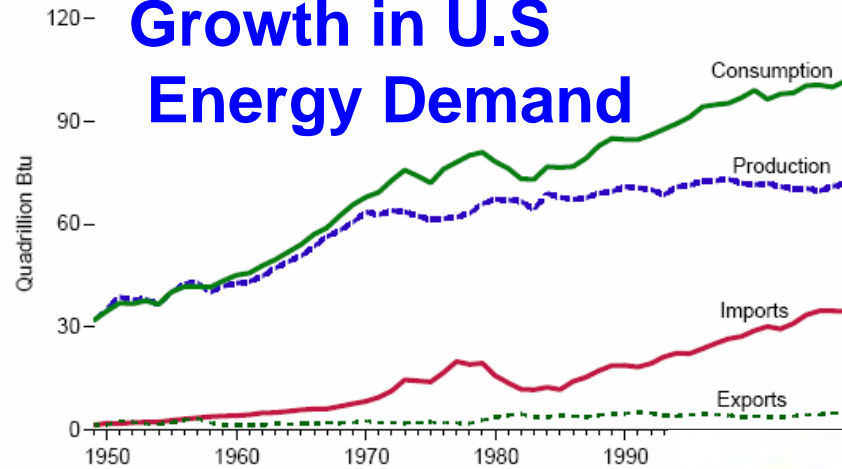
Of course, as the oceans catch up, the atmosphere will increase further because then the oceans exert less cooling on it.

It appears that, for a given constant climate forcing, the ocean's top layers can reach a good chunk of the new temperature equilibrium with the atmosphere in few decades, but to reach full steady state will take a thousand years because that's how long it takes the circulation to replace deep waters.

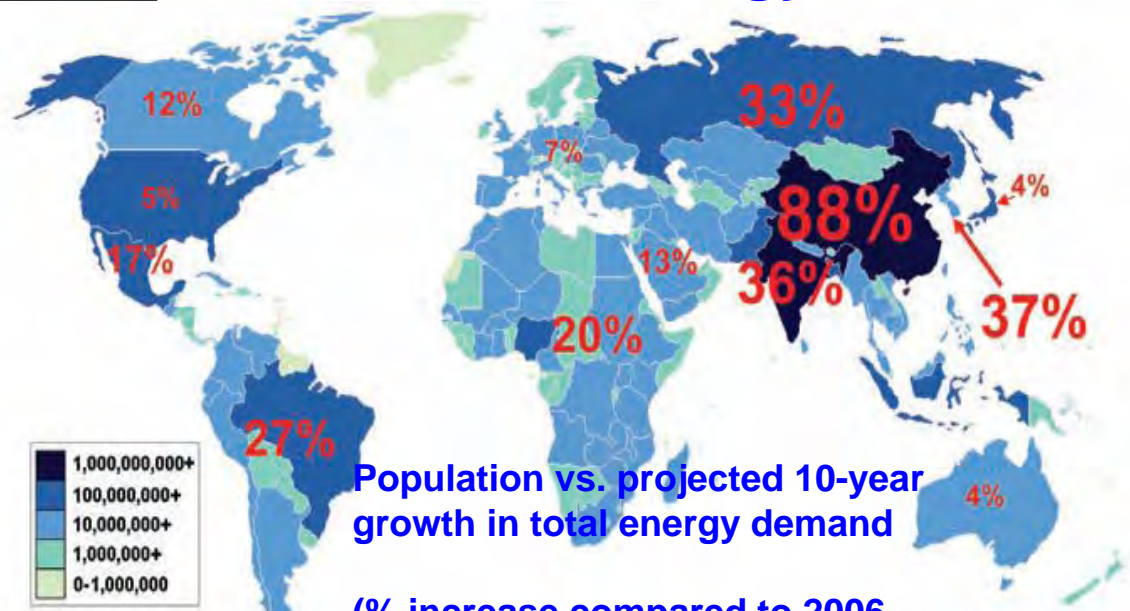


Overview, 1949-2007

Growth in U.S Energy Demand



Growth in Global Energy Demand

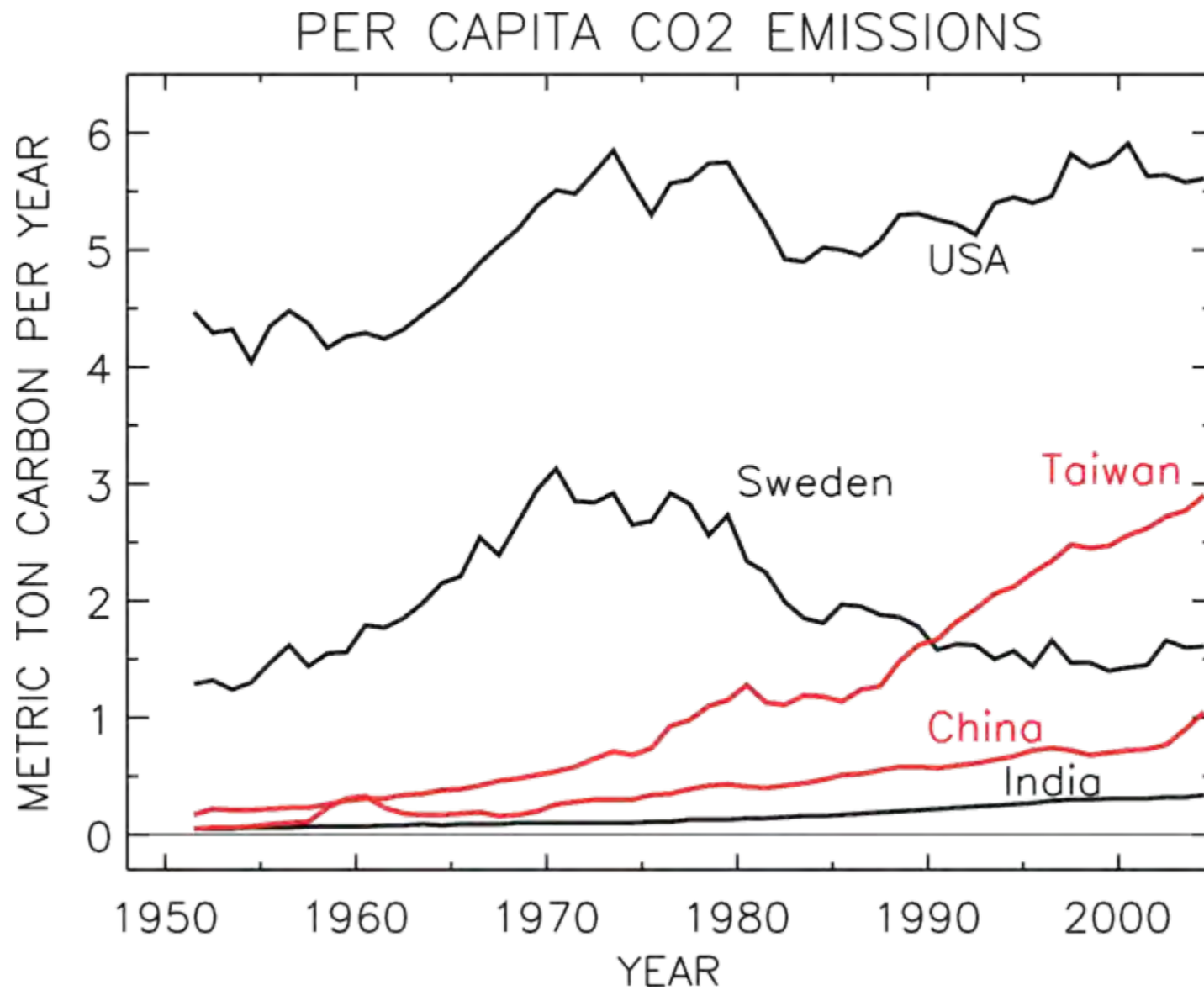


Population

Population vs. projected 10-year growth in total energy demand

(% increase compared to 2006 value in each country) per capita

THE THREE DELAYS





NOAA's Mission



To understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social, and environmental needs.



NOAA's Crucial Role

- **NOAA is responsible for national observation networks, operational weather forecasts, and climate models. These have not been optimized for the field of renewable energy and are insufficient for this field (RE).**
- **NOAA has modernized sections of its information and services to meet the needs of other industries in the past, e.g., aviation industry.**
- **If NOAA does not meet the evolving needs of the renewable-energy sector, other governmental agencies will be forced to develop meteorological observation networks and forecast capabilities that fall within the scope of NOAA's mission.**
- **NOAA must enhance its measurements and modeling capabilities to meet the needs of the renewable energy industry and the nation.**

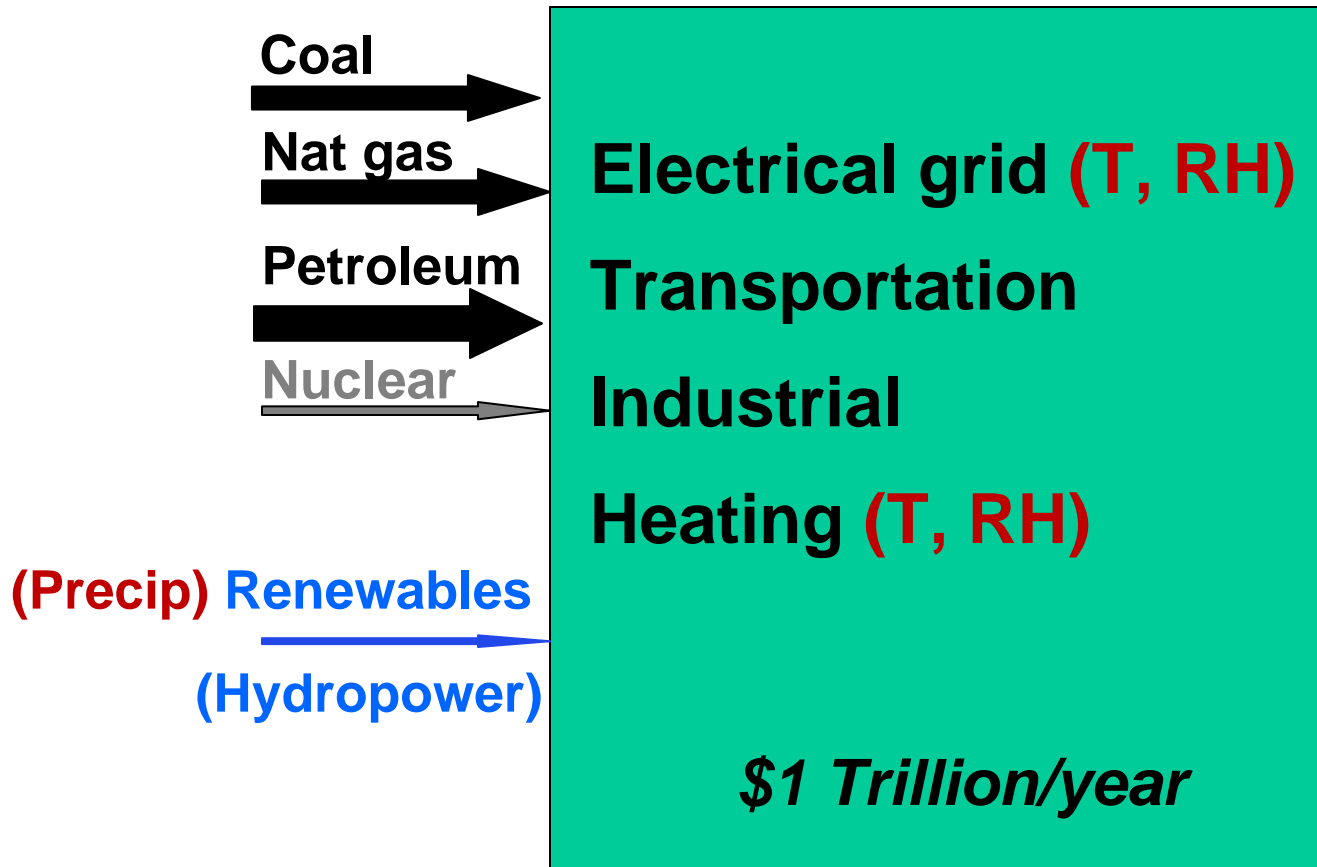


Multiple Federal Agencies Will Have to Cooperate to Solve the Energy-Climate-Economic Crisis

- Department of Energy
- Environmental Protection Agency
- Federal Energy Regulatory Commission
- Department of the Interior
- U.S.G.S
- NOAA's mission is to *predict and understand changes in Earth's environment* and conserve and manage coastal and marine resources to *meet our nation's economic, social and environmental needs.*



2007 US Energy Flows



Modest impacts
of meteorology
on demand:

T=Temp

RH= Relative
Humidity

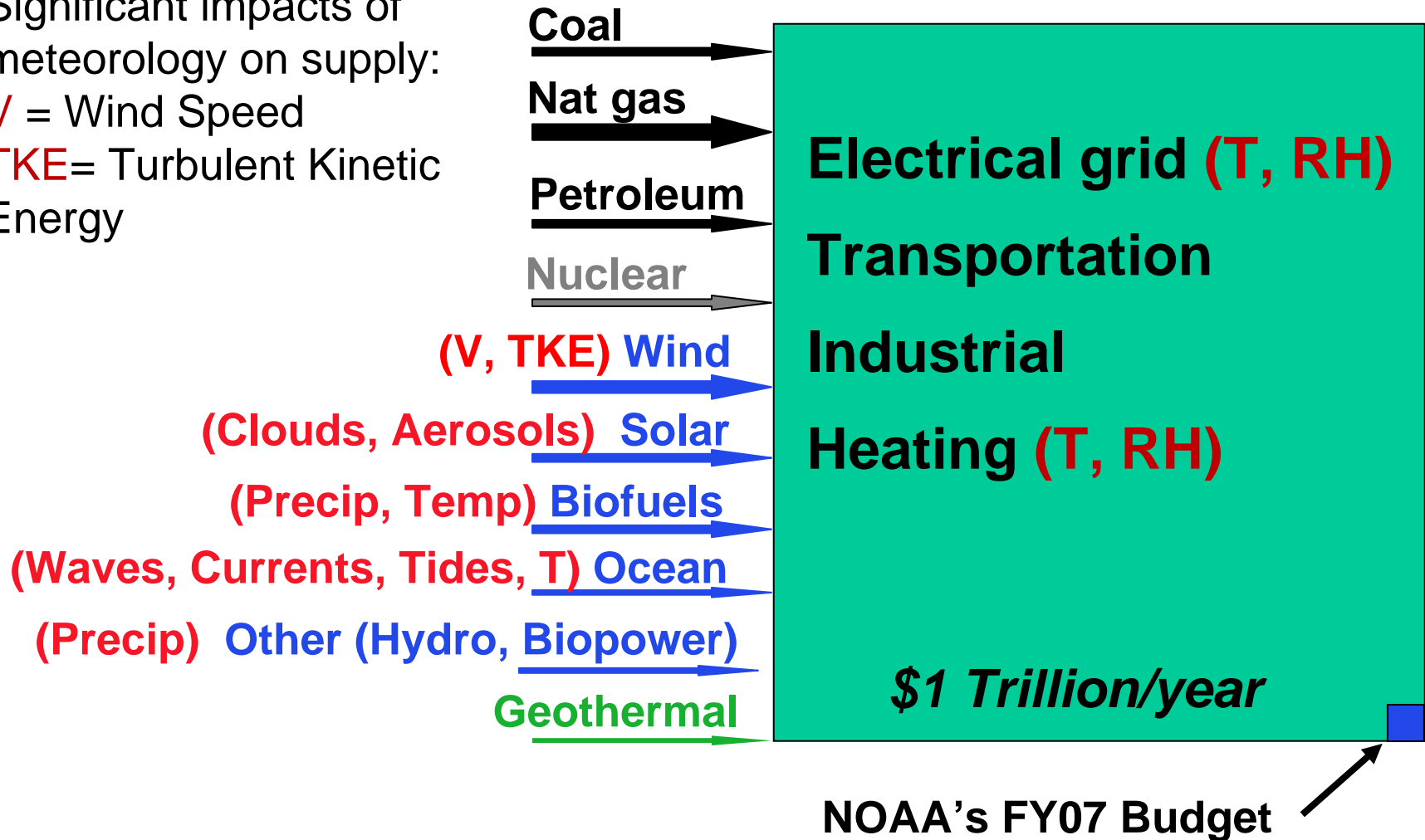


2030 US Energy Flows?

Significant impacts of meteorology on supply:

V = Wind Speed

TKE = Turbulent Kinetic Energy





Collaboration between NOAA ESRL & NREL

New, monthly seminar hosted by NOAA ESRL & DOE NREL

www.esrl.noaa.gov/research/events/seas/

Diverse audience, e.g., CU, private industry, public

Kick-off was on Oct. 30

www.esrl.noaa.gov/research/events/seas/past_seminars.html

**Letter of Intent signing with Sandy MacDonald,
Director of NOAA ESRL; Andy Karsner, DOE
DUS for Renewable Energy; and Dan Arvizu,
CEO of NREL. July 31, 2008.**

Currently developing an MOU with NREL





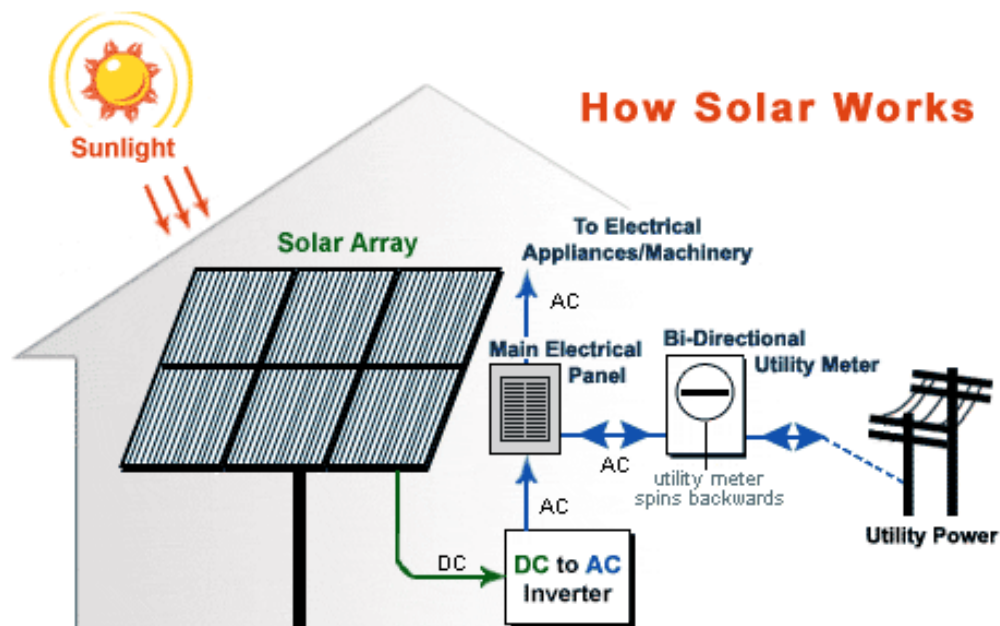
NOAA - Relevant Issues for Wind

- **Insufficient observations of wind at the height of wind turbines (20 -200 m)**
- **Need improved understanding of:**
 - mesoscale processes
 - planetary boundary layer
 - complex terrain effects
 - upwind turbine effects
- **Need to explore co-variability of wind power potential across grid, in particular for extremely low and high tails of the distribution**
- **NOAA holds the expertise to do this work**
- **To realize CO₂ savings, grid operators must have confidence in wind forecasts to offset fossil fuel plants**



NOAA-Relevant Issues for PV and CSP

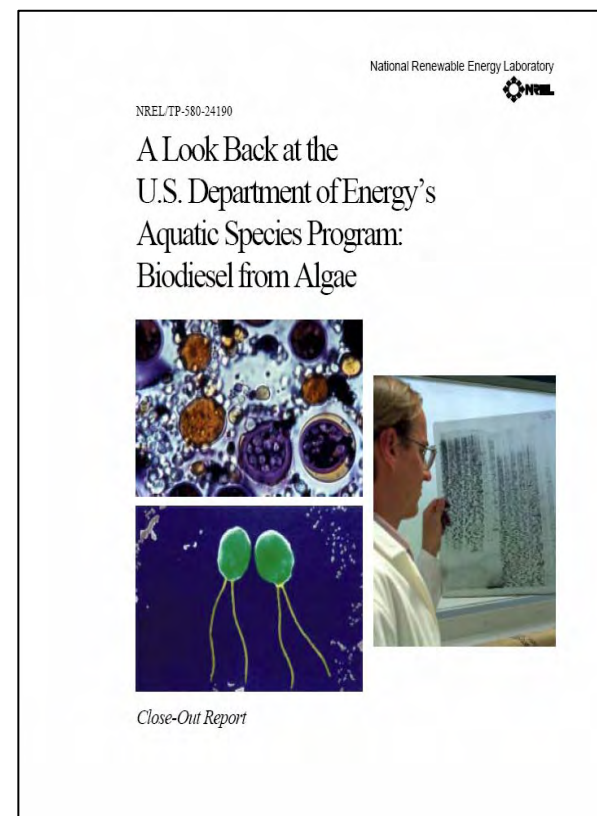
- Insufficient observations of solar radiation (direct and total)
- Need improved forecasts across a range of time scales of sun (clouds & aerosols) to help integrate CSP into grid (balance supply with demand)
- Need to know co-variability of wind and solar energy
- NOAA has the expertise to do this work





NOAA-Relevant Issues for Biomass/Biofuels

- The National Integrated Drought Information System (NIDIS)
- Improve forecasts of precipitation and drought, which would help crop producers, e.g., through irrigation scheduling
- Monitor the impacts on weather and climate of land-use changes
- Impacts on local & regional weather of land-use change, e.g., flood 20 million acres in AZ
 - to yield 6 billion barrels algal oil/year
 - Could influence N. American monsoon
- Yesterday, DOE JJohn Ferrell and Joyce Yang explained addition to forecasts of precipitation and drought, forecasts of sunshine, temperature, wind, fires (especially catastrophic fires, which emit, e.g., GHGs and aerosols), evapotranspiration.



govdocs.aquake.org/cgi/reprint/2004/915/9150010.pdf



NOAA's Capabilities to Advance Renewable Energy

NOAA ESRL has the capability to:

- Deploy observing networks**
- Improve weather forecasts**
- Improve weekly to seasonal weather and climate forecasts**
- Improve climate models and diagnosis (understanding climate processes)**

- Outcomes (benefits to society) include:**
 - Improvements in short-term forecasts will provide grid-operator information about how much spinning-reserve power they need to have in the near future to meet demand.**
 - Improvements in medium-range to seasonal forecasts could help the energy industry in planning for seasonal needs.**
 - Climate models that include RE and energy demand would assist DOE and industry estimates of long-term energy demand.**



ASOS Sites

- Develop 1-km National Weather Models with Hourly Updating as a Backbone to RE Guidance Infrastructure
- Develop a Wind-energy Testbed Improve fundamental understanding of mesoscale and local flows that have proved critical to wind-energy operations.
- Improve quantitative forecast skill for mesoscale and local flows in NWP models by improving representation of physical processes at wind-turbine heights
- Develop and deploy new instruments and observational strategies, and data distribution and visualization tools
- Develop seasonal forecasts products that address regional wind energy potential in the U.S
- Develop climate forecasts of seasonal wind energy potential



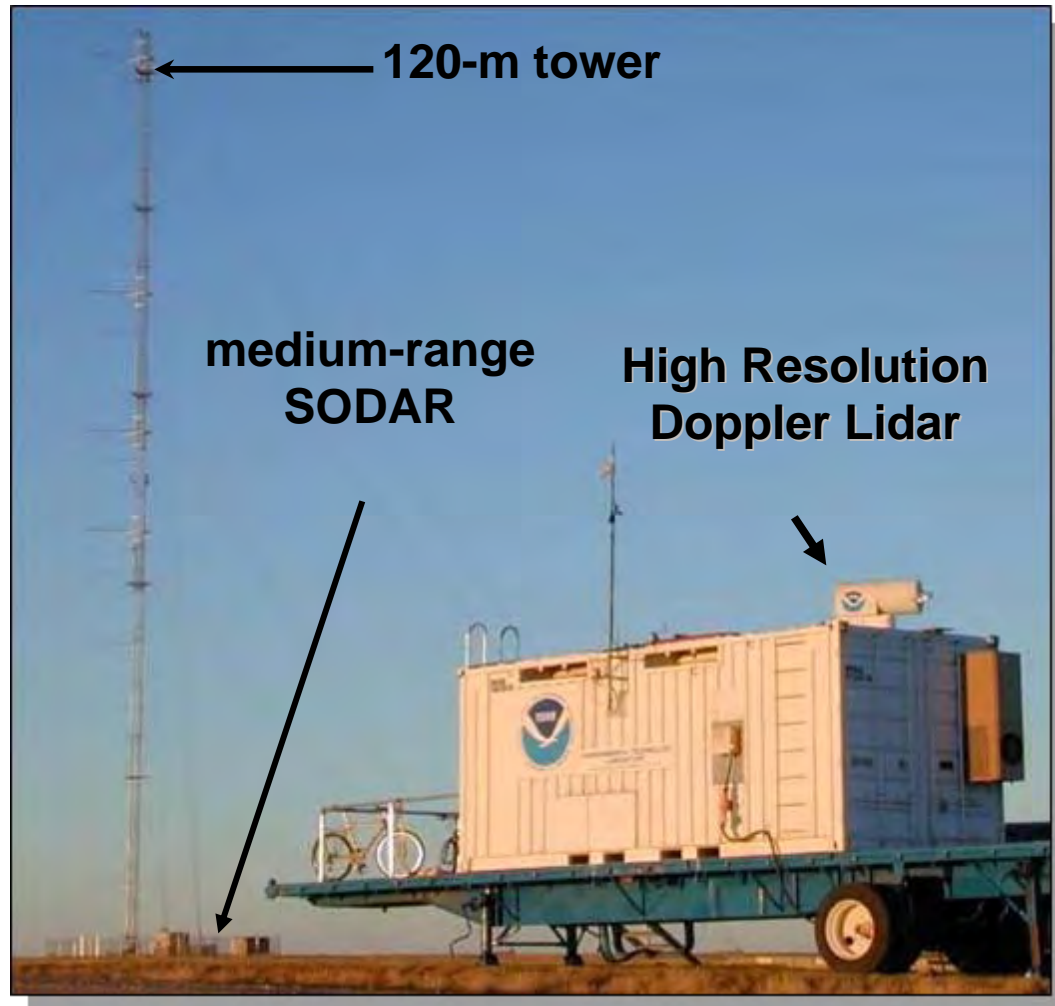
NOAA Profiler Network



Doppler lidar



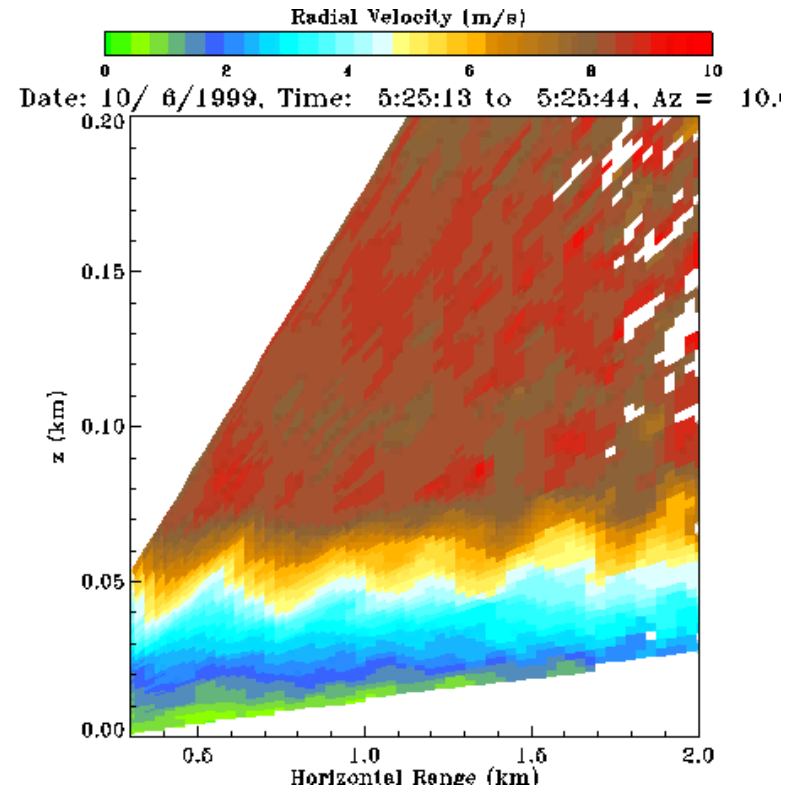
NOAA has Specialized Instruments for Studying Wind



120-m tower

medium-range
SODAR

High Resolution
Doppler Lidar



ESRL could expand and
refine this research.

*Neil Kelly (NREL) & Bob Banta, Yelena Pichugina
(NOAA), Lamar, Sept. 2003. Studied Low-Level Jet.*



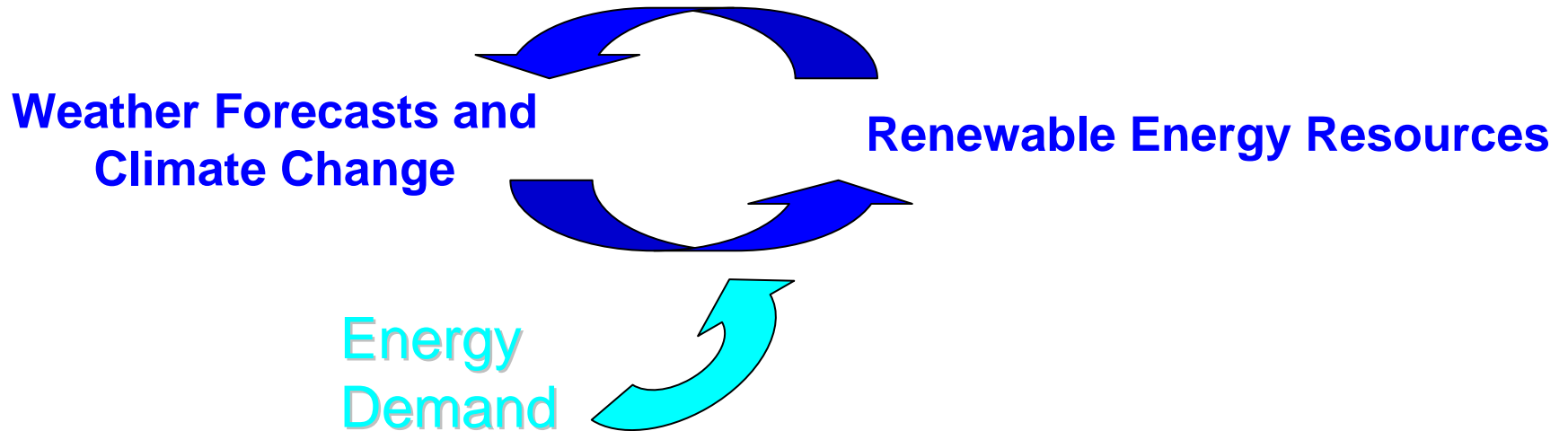
Examples Targets for Support NOAA Could Offer for Solar Energy

- **Acquire enhanced solar observational database to help evaluate current and future solar resource for spatial and temporal variability.**
- **Enhance ability to infer direct solar radiation at the surface from satellite data using these validation datasets.**
- **Improve cloud forecasts in models and fundamental understanding of clouds.**
- **Develop and validate surface solar radiation forecast products (direct and total).**
- **Assimilate current aerosol and albedo data into forecast models.**
- **Develop seasonal forecasts products that address regional solar energy potential in the U.S.**
- **Develop data distribution and visualization tools.**





NOAA ESRL Could Develop a Coupled Energy-Climate Model to Support RE





Summary of Opportunities

- **NOAA can make essential contributions to acceleration of deployment of RE**
 - Deploy observing networks
 - Improve weather forecasts
 - Improve climate models and diagnosis
- **Improvements in short-term forecasts would:**
 - Help integrate renewable energy into the electric grid,
 - Help balance energy demand with energy supply,
 - Provide grid-operator information about how much spinning-reserve power they need to have in the near future to meet demand.
- **Coupled energy-climate models would:**
 - Support DOE and industry estimates of long-term energy demand.
 - Improve understanding of impact of changing weather and climate on RE, & vice versa.
- **Expanding RE would increase the nation's energy security, provide good "green" jobs, thereby boosting the economy, and reduce emissions of CO₂.**
- **If NOAA does not meet the evolving needs of the renewable-energy sector, other governmental agencies will be forced to develop meteorological observation networks and forecast capabilities that fall within the scope of NOAA's mission.**

Summary



Since the IPCC WG1 AR4 was published last year, interesting observations and improved understanding of polar processes have occurred.

CO₂ in the atmosphere lasts a long time. 20% of what we emit today exists for over a thousand years.

NOAA has the expertise to collect the data, improve weather forecasts, enhance climate, and improve basic understanding of fundamental processes to accelerate deployment of renewable energy in the U.S.

We want to work with NREL and others in the field of RE to serve the nation.



Thanks for listening.

Summary

- Forcing: Greenhouse gases are at unprecedented levels, and aerosol offsets are better quantified.
- Observations: *Global warming and beyond*: Discernible human influences on other aspects of climate including ocean warming, temperature extremes, changes in wind patterns, precipitation changes and more.

Attribution: Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (>90%) due to the observed increase in anthropogenic greenhouse gas concentrations.

- Projections: Already committed to more warming (next few decades) even for constant composition, with choices about emissions affecting the longer term more and more.
 - Expected future earth system changes: *likely to virtually certain*: more extremes, wet in some places, dry in others, etc...
 - Long term: Sustained warming for millennia could cause Greenland to melt, producing meters of sea level rise... What we do (not) do now makes a big difference in the future.

2007 Arctic SI min refs

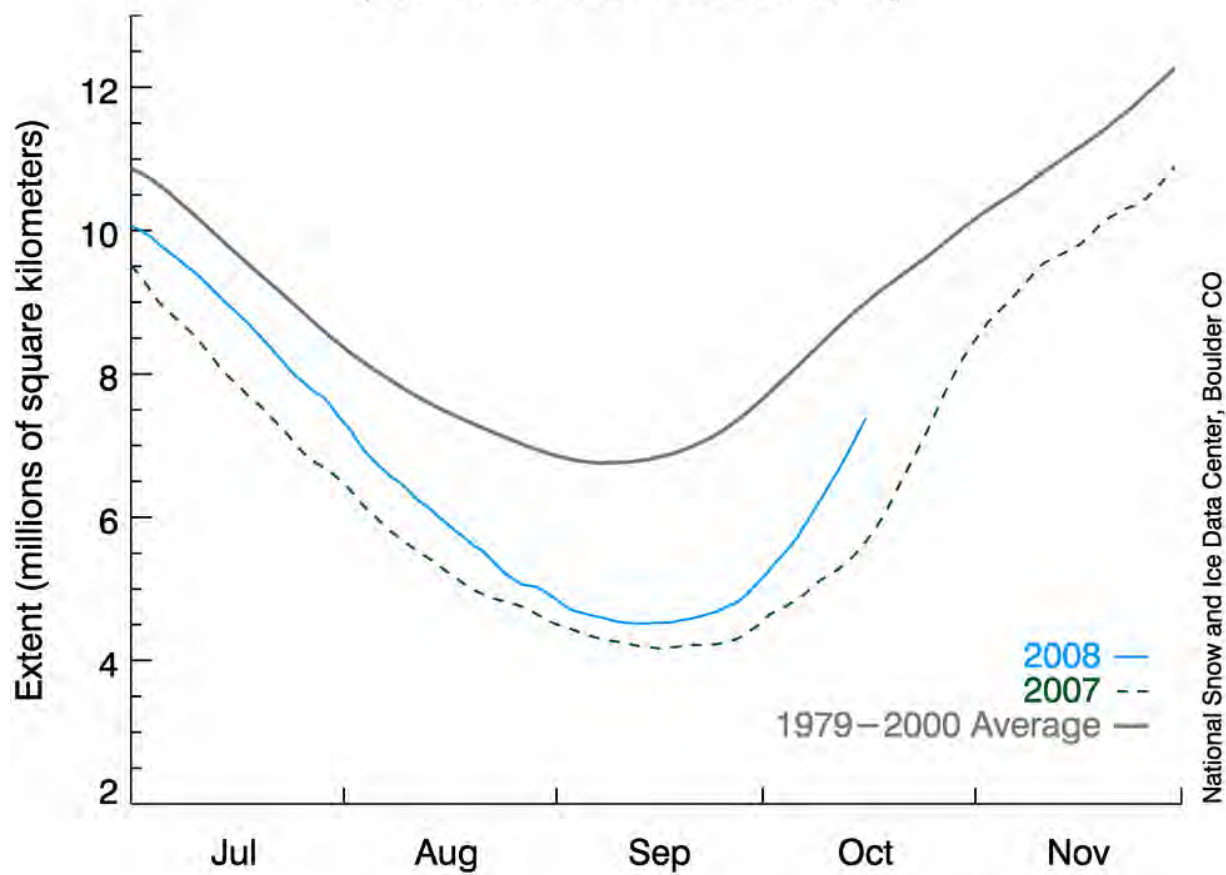
- Schweiger A. J., J. Zhang, R. W. Lindsay, M. Steele (2008), Did unusually sunny skies help drive the record sea ice minimum of 2007?, Geophys. Res. Lett., 35, L10503, doi:10.1029/2008GL033463.

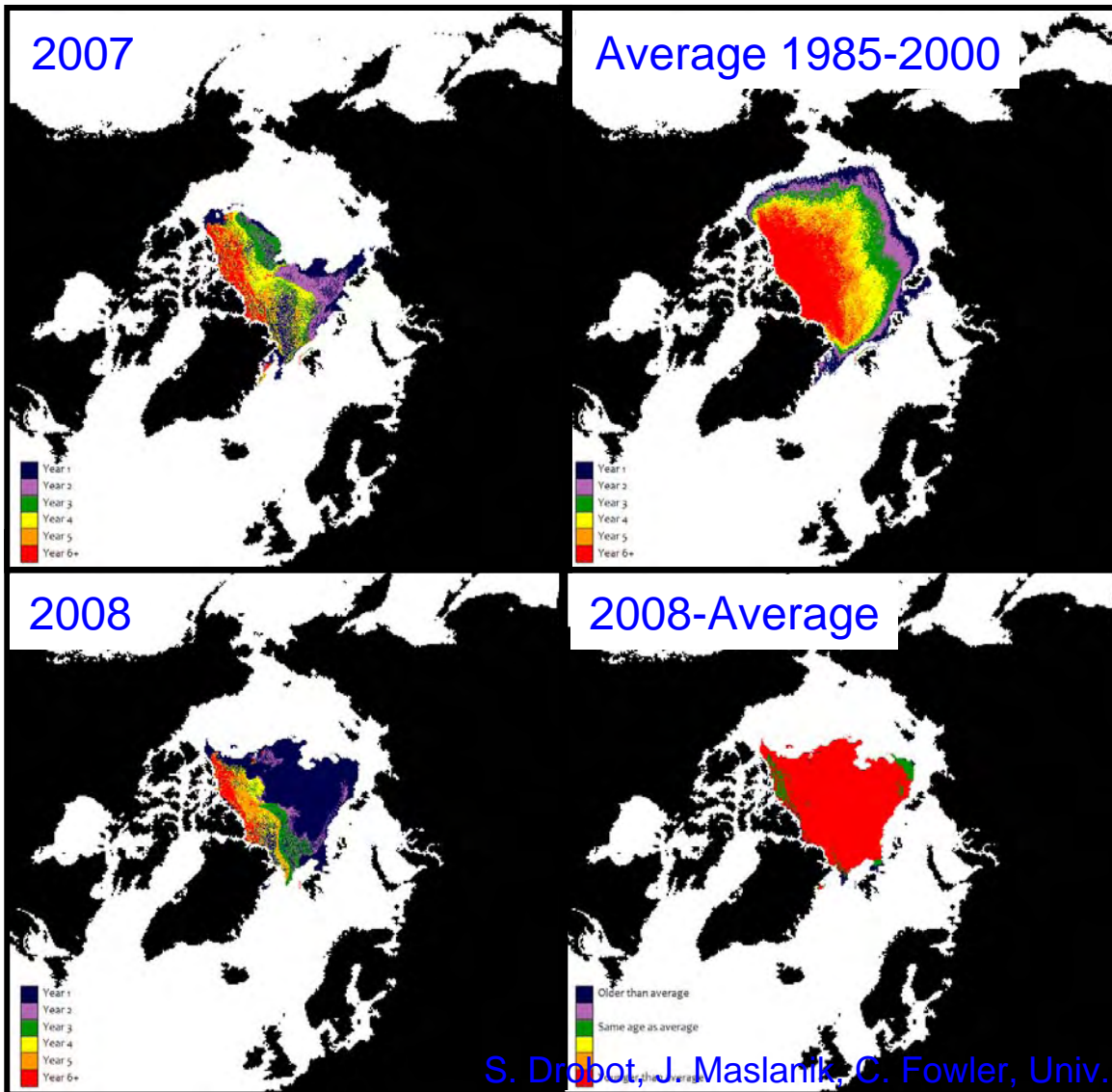
Zhang J., R. Lindsay, M. Steele, A. Schweiger (2008), What drove the dramatic retreat of arctic sea ice during summer 2007?, Geophys. Res. Lett., 35, L11505, doi:10.1029/2008GL034005.

Kay J. E., T. L'Ecuyer, A. Gettelman, G. Stephens, C. O'Dell (2008), The contribution of cloud and radiation anomalies to the 2007 Arctic sea ice extent minimum, Geophys. Res. Lett., 35, L08503, doi:10.1029/2008GL033451.

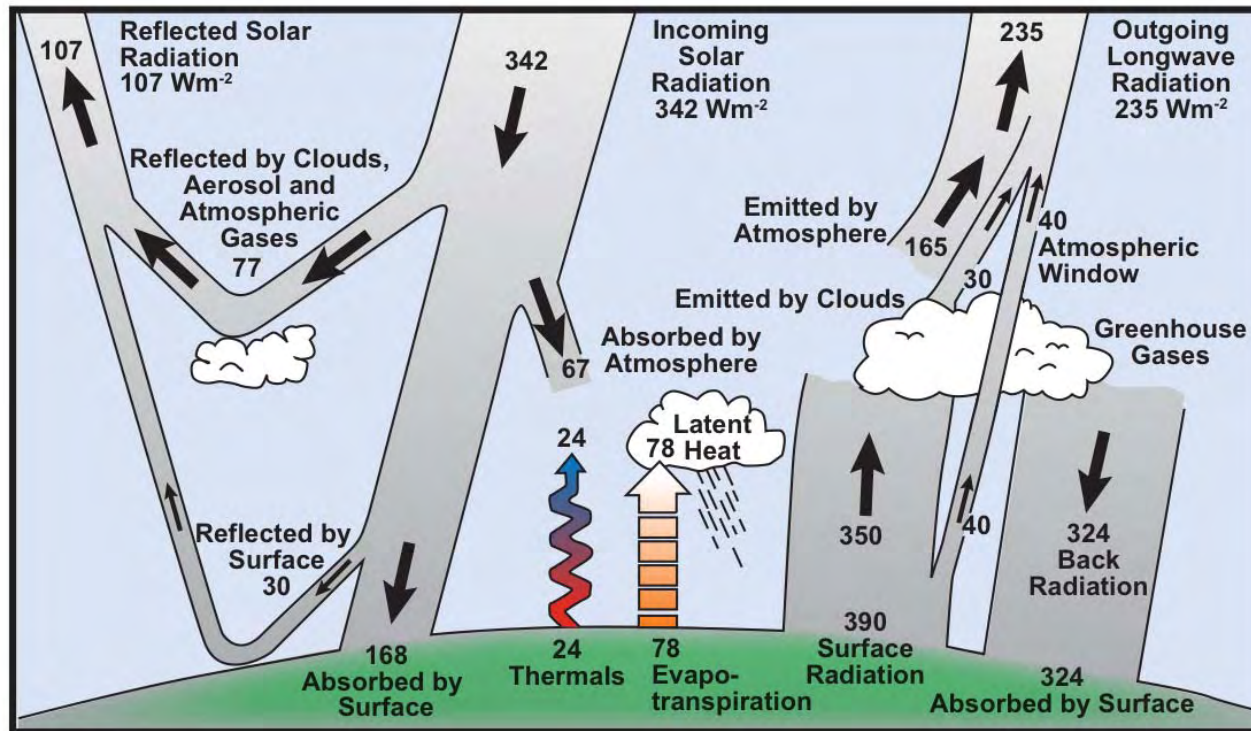
Stroeve, J., M. Serreze, S. Drobot, S. Gearheard, M. Holland, J. Maslanik,

Arctic Sea Ice Extent (Area of ocean with at least 15% sea ice)





Estimate of the Earth's annual and global mean energy balance.



Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).

Table SPM-1. Observed rate of sea level rise and estimated contributions from different sources. {5.5, Table 5.3}

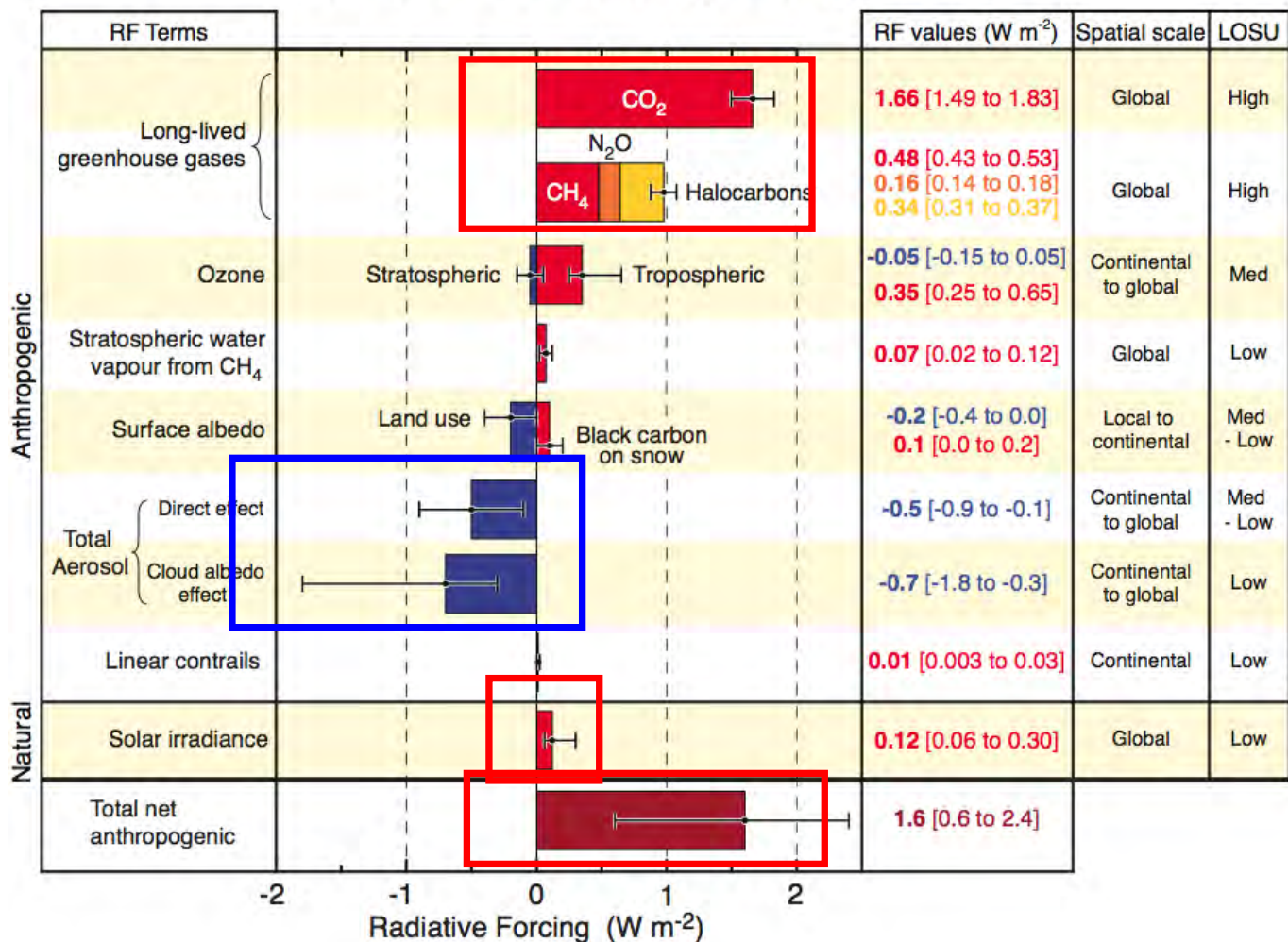
Source of sea level rise	Rate of sea level rise (mm per year)	
	1961 – 2003	1993 – 2003
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and ice caps	0.50 ± 0.18	0.77 ± 0.22
Greenland ice sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheet	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	2.8 ± 0.7
Observed total sea level rise	1.8 ± 0.5^a	3.1 ± 0.7^a
Difference (Observed minus sum of estimated climate contributions)	0.7 ± 0.7	0.3 ± 1.0

Table note:

^a Data prior to 1993 are from tide gauges and after 1993 are from satellite altimetry.

Human and Natural Drivers of Climate Change

Radiative Forcing Components



Human and Natural Drivers of Climate Change

- Carbon dioxide is the most important anthropogenic greenhouse gas.
- The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005.
- The atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650,000 years (180 to 300 ppm) as determined from ice cores.
- The annual carbon dioxide concentration growth rate was larger during the last 10 years (1995–2005 average: 1.9 ppm per year), than it has been since the beginning of continuous direct atmospheric measurements (1960–2005 average: 1.4 ppm per year) although there is year-to-year variability in growth rates.

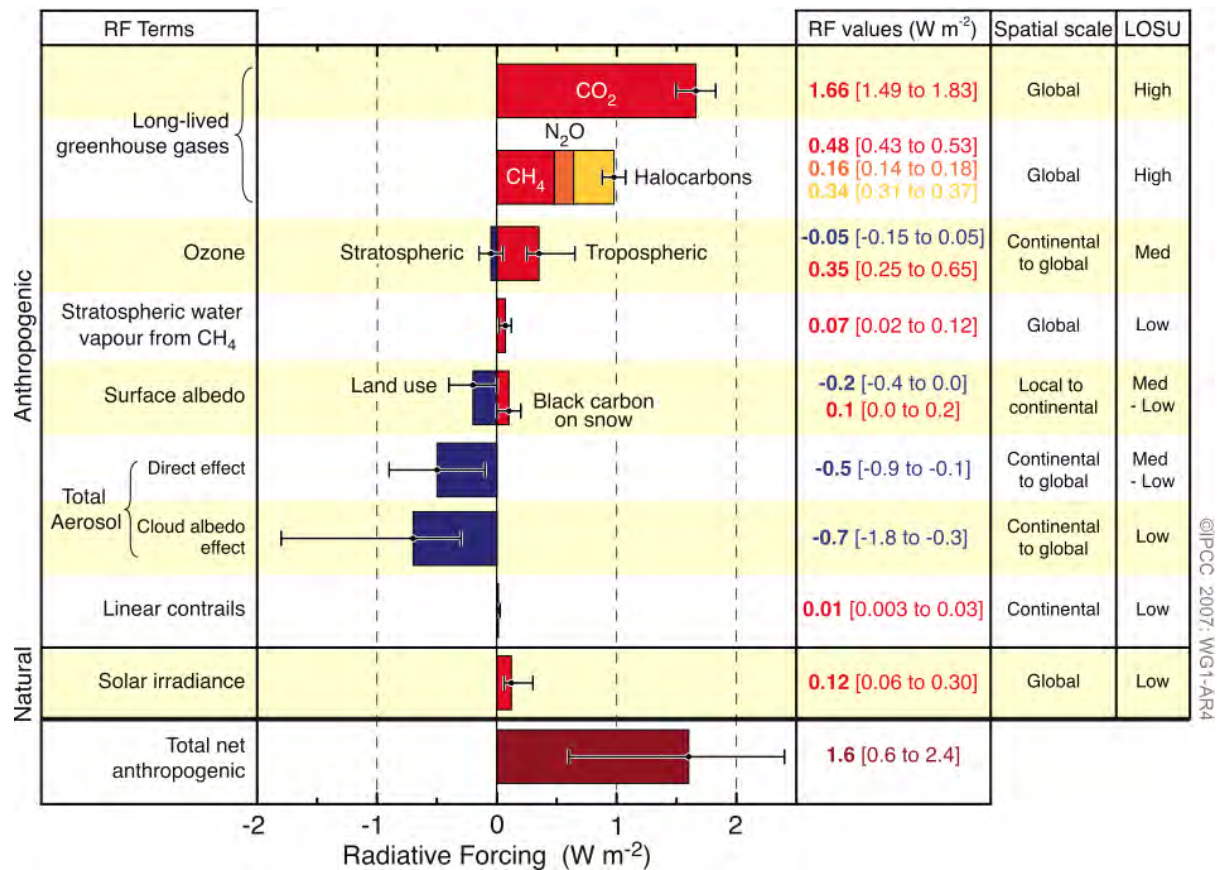


Figure SPM.2

ARCTIC REGION

